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SMOKE EMISSIONS FROM AIRCRAFT INTERIOR MATERIALS AT ELEVATED HE--ETC(U)
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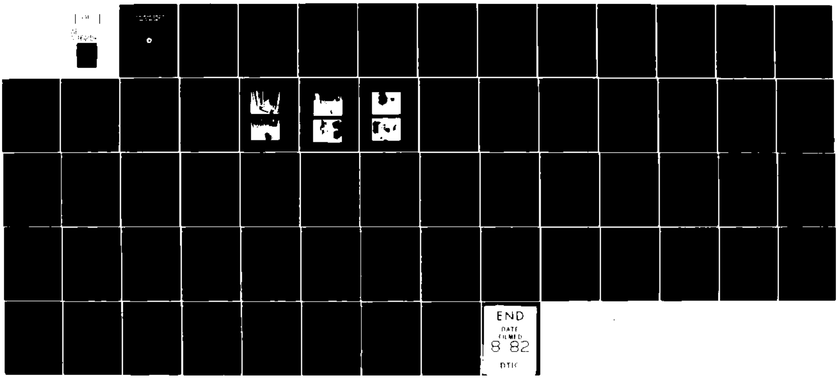

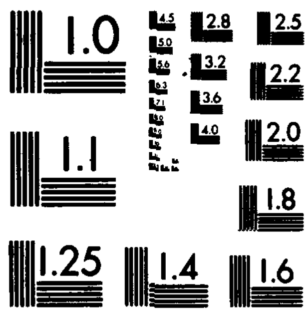
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REPORT NO. FAA-RD-79-26
NA-79-6

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SMOKE EMISSIONS FROM AIRCRAFT INTERIOR MATERIALS AT ELEVATED HEAT FLUX LEVELS USING MODIFIED NBS SMOKE CHAMBER

Louis J. Brown, Jr.

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JULY 1979

FINAL REPORT

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16. Abstract

The National Bureau of Standards (NBS) smoke chamber is a widely used instrument for measuring smoke emitted from materials when exposed to radiant heat and flame sources. The standard NBS chamber, however, lacks the capability of spanning the range of realistic heat flux levels experienced from a jet fuel fire. In order to provide this flexibility, a variable radiant heat flux Mellen furnace capable of reaching 10 British thermal units per square foot second (Btu/ft^2 s) was installed in the chamber. Also, a radiometer was mounted in the chamber for calibration of the furnace and a load cell was installed beneath the sample holder to monitor weight loss of test specimens. Finally, a laser transmissometer was mounted to allow comparisons with the standard photometric system supplied with the chamber. These modifications resulted in a more versatile laboratory test for characterizing material smoke emissions when exposed to radiant heat and flame, and for correlating laboratory and full-scale fire test results. Fifteen aircraft cabin materials were tested at 2.2, 5.0, 7.5, and 10 Btu/ft^2 s for piloted and nonpiloted exposure. For most of the materials tested, smoke production increased with increasing heat flux provided the sample did not ignite. Polycarbonate and polysulfone sheeting, wool carpet and PVC/ABS flooring produced considerably more smoke at heat flux levels above the "standard" 2.2 Btu/ft^2 s value. It was concluded that the "standard" 2.2 Btu/ft^2 s heat flux is insufficient for evaluating the smoke characteristics of cabin materials in a postcrash cabin fire situation where a higher and wider range of heat flux levels exists.

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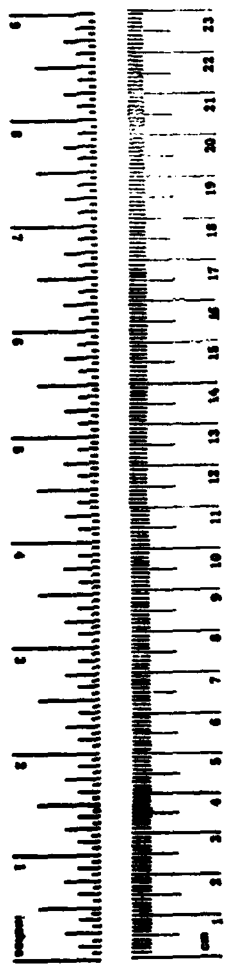
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

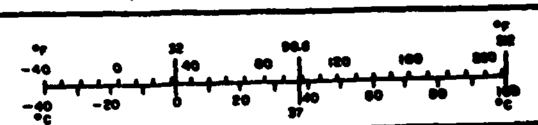
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

The purpose of this project was to extend the heat flux range and test capabilities of the standard National Bureau of Standards (NBS) smoke chamber in order to better simulate cabin fire environments. Another objective was to evaluate the smoke emission characteristics of a series of aircraft interior materials over a wide range of heat flux conditions simulating those typical of a cabin fire environment.

BACKGROUND.

The smoke from burning materials presents a severe obstacle to survival. In the case of a survivable aircraft crash with a resulting cabin fire, smoke can prevent rapid passenger egress by visual obscuration of emergency exit signs and doors.

Although full-scale tests can characterize environmental conditions of a simulated cabin fire, small-scale tests are needed to provide uniform laboratory conditions for routine material characterization. The standard NBS smoke chamber is widely used in government and industry to evaluate smoking tendencies of materials at a fixed radiant heat flux of 2.2 British thermal units per square foot second (Btu/ft^2 s) (2.5 watts per square centimeter (w/cm^2)) (references 1 and 2). The chamber consists of an 18-cubic-foot (ft^3) enclosed box, a vertical specimen holder, a radiant heater, a propane-air burner, and a photometric system using an incandescent lamp and phototube receiver. Modifications were made to cause more severe material combustion over a range of realistic heat flux levels and provide more data on material behavior. In order to obtain these goals, the modifications made to the chamber consisted of adding a variable radiant heat flux furnace capable of reaching 10 Btu/ft^2 s (11.4 w/cm^2), a laser transmissometer as an alternate means of measuring smoke density, and a load cell for continuous weight loss measurement of the test material.

TEST MATERIALS.

Fifteen interior materials were selected for testing in the modified NBS smoke chamber. These materials were chosen from the following five usage categories: fabrics (4), flooring (2), foams (2), panels (5), and plastics (2). A more detailed description of these test materials is found in appendix A.

Fourteen of the test materials, which were obtained from airframe and seat manufacturers, are used in the three types of wide-bodied jets; the remaining material, polysulfone (No. 220), is under consideration for aircraft usage. These materials were prepared for testing in accordance with the NBS smoke chamber standard procedure (reference 1).

DISCUSSION

NBS CHAMBER MODIFICATIONS.

The modifications to the standard NBS smoke chamber were guided by published results of similar smoke measurements in the last 5 years (references 3 and 4). In order to complete the chamber modification, the following items were installed:

- Mellen furnace
- Heat flux transducers (2)
- Load cell
- Laser photometer
- Volt-pac® variable transformer

The special Mellen model 10 furnace, capable of reaching 10 Btu/ft^2 s (11.4 w/cm^2), was connected to a General Electric (G.E.) model 9T92Y37 variable transformer and was bench tested. The furnace was allowed to "bake-in" according to manufacturer specifications and was then mounted on a slider mechanism fabricated from 1-inch steel angle, 3/8-inch-diameter stainless steel rods (2), and machined aluminum blocks (2) containing Teflon® bushings (two each) (figure 1).

The slider mechanism for the furnace was necessitated by the use of a load cell, Transducer Inc. model BCL-PP462-CS-1-C10P1, under the specimen holder which remains stationary over the test duration. This differs from the standard chamber in which the furnace is rigidly mounted, and the specimen holder is slid along two rails. Using a slider mechanism enables the operator to move the furnace back and forth from a shielded calibrating position (figure 2) to a testing position (figure 3). Movement is accomplished with an external hydraulic lever actuator-receiver system (figure 4). A pulley system (figure 5) operates a shield which prevents any preheating of the test specimen while the furnace is in the calibrate position.

The furnace was attached to two aluminum blocks, each containing two teflon bushings through which the stainless steel rods were placed. The rods, in turn, were secured to the steel angle frame providing a track for the forward and back motion. The entire assembly was fastened to the chamber floor, placing the Mellen furnace in the same test position as the original heater supplied with the chamber. The load cell was mounted beneath the chamber floor to shield it from the harsh environment within the chamber. A support rod, which was fabricated and attached to the load cell, protruded up through the chamber floor and contained a mount for the specimen holder (figure 1). This mechanism enabled the operator to easily place and remove each sample being tested.

A radiometer (Hy-cal Engineering model 8015) was mounted on the back wall of the chamber for calibrating the radiant heat output of the furnace (figure 1). A second radiometer was used to periodically check the accuracy of the installed radiometer. The helium-neon laser (Spectra Physics, model 155) had a wavelength of 632.8 nanometer (nm) and was mounted below the chamber floor and aimed vertically. Its beam shone through specially installed floor and ceiling chamber windows at the photocell receiver (Weston, model 856YR) attached on top of the chamber (figure 6). The laser was located in the front left corner of the chamber adjacent to the standard photometric system which was supplied with the chamber. Mounting the laser transmissometer in this manner accounts for differences due to smoke stratification within the chamber and allows for direct comparison of transmittance data with the standard photometric system. Finally, all exposed steel (nuts, bolts, etc.) within the chamber were coated with a chemical-resistant epoxy paint. No changes were made to the standard "pilot light" ignition feature incorporated in the standard chamber to measure smoke under flaming conditions.

TEST RESULTS AND ANALYSIS.

Tests were conducted in both piloted and nonpiloted modes at 2.2, 5.0, 7.5, and 10.0 Btu/ft^2 s for a total of 230 tests. The nonpiloted mode refers to exposure to radiant heat only; whereas, the piloted mode refers to exposure to radiant heat and a flaming ignition source. Piloted tests were performed with the standard multidirectional burner along the bottom edge of the test specimen (reference 1). It was decided to discontinue use of the laser transmissometer because of heavy deposition of soot particles on the bottom window which blocked the laser beam and produced very low light transmittance data. The standard photometric system has a much wider light beam and an electrical heater for reducing deposition; consequently, it is less susceptible to this problem. Therefore, the standard photometric system was used as the primary source for smoke density measurements. Light transmittance and weight loss data versus time were recorded for each test with a two-channel Honeywell model Electronik 196 pen recorder. Specific optical density versus time at each test condition was calculated and plotted at 0.1-minute intervals on a Hewlett Packard 9210 computer-plotter (appendix B). For 2.2 Btu/ft^2 s piloted and nonpiloted tests and 5.0 Btu/ft^2 s piloted tests, three samples of every material were tested. In calculating specific optical density plots, the sample producing results closest to the average of the three was used rather than an average of the three. This was done to simplify weight loss versus specific optical density comparison. For the remaining exposure conditions, only one sample of each material was tested.

In the initial calibration of the furnace, discrepancies were found between the heat flux measurements taken with the Aminco radiometer supplied with the chamber and the Hy-cal radiometer, which contained a sapphire window. Differences as high as 50 percent were noted between these two instruments. Further investigation into the problem showed these discrepancies were due to basic differences in calibration techniques between manufacturers. Comparison of the Aminco radiometer and the Hy-cal radiometer without a window, averaged over the area of the Aminco radiometer, produced agreement within 15 percent. Since this agreement is reasonable, it was decided to use the Hy-cal radiometer (necessitated by the high heat flux operating range) without a window in calibrating the Mellen furnace.

For the 15 materials tested, smoke production usually increased with increasing heat flux, provided the sample did not ignite. This was true for both piloted and nonpiloted conditions. When ignition of the material occurred, smoke production would decrease for most materials, as observed during individual tests. Material numbers (Nos.) 210, 226, 230, and 235 were exceptions to this behavior. These materials, which were four of the six highest smokers (displaying a specific optical density (D_s) of greater than 600), exhibited even higher smoke emissions when ignition of the sample occurred. The decrease in smoke production when ignition occurred in the other 11 materials tested is probably due to more complete material combustion.

The following is an analysis of the smoke history data contained in appendix B on the basis of grouping the materials into five usage categories.

FABRICS. A smoke limit once considered for fabrics was $D_s \leq 100$ at 4 minutes for a 2.2 Btu/ft^2 s exposure (reference 5). A bar graph (figure 7) shows the behavior of the four fabrics tested in relation to this criteria. Treated nylon (No. 209), in piloted tests, passed this criteria for all heat flux levels tested. Nonpiloted tests of No. 209 only passed the criteria for 2.2 Btu/ft^2 s. Material No. 209 was the lowest smoker per unit sample weight in this usage category. Except for the 10-Btu/ft^2 s nonpiloted test condition, 100-percent wool (No. 212) nonpiloted tests passed the limit for fabrics. The only piloted test of No. 212 that passed the limit was at 7.5 Btu/ft^2 s. Material No. 204, which is wool/nylon 90/10 percent, passed the assumed limit for fabrics only at 2.2-Btu/ft^2 s nonpiloted and 10-Btu/ft^2 s piloted conditions. This is an interesting result because a piloted test of No. 204 produced more smoke than a nonpiloted test at 2.2 Btu/ft^2 s; whereas, the nonpiloted test of No. 204 at 10.0 Btu/ft^2 s produced significantly more smoke than the piloted test. This clearly shows the importance of varying the heat flux and exposure mode while observing the smoking characteristics of this and other materials. Material No. 210, Naugafoam, produced significantly more amounts of smoke than the other three fabrics at all heat flux levels. For No. 210, the 7.5 Btu/ft^2 s and 10 Btu/ft^2 s piloted and nonpiloted tests produced a maximum specific optical density (D_m) of greater than 650 in less than 90 seconds.

FLOORING. Only two flooring materials were tested: a vinyl/ABS laminate, No. 230, and a wool carpet, No. 226 (see figures B-9 through B-12). For both materials, there was a significant change in smoke production between 2.2 and 5.0 Btu/ft^2 s with nonpiloted exposures. Except for nonpiloted exposure of No. 226, there was very little difference noted in smoke production between 5.0, 7.5, and 10.0 Btu/ft^2 s. Wool carpet generally smokes less than vinyl flooring when exposed to varying heat flux levels; but of the materials tested, flooring as a group produced the most smoke. The specific optical density limits for materials other than fabrics were 100 at 90 seconds and 200 at 4 minutes (reference 5). Both materials only passed this limit at 2.2-Btu/ft^2 s nonpiloted exposure, which is the mildest test condition.

FOAMS. Only two polyurethane foam materials were tested: No. 213 (figures B-13 and B-14) and No. 215 (figures B-15 and B-16). Material No. 215 displayed slightly lower levels of smoke production than material No. 213. Piloted exposure tests showed very similar smoking characteristics over a range of heat fluxes for each material, respectively. This probably indicates that smoke production is dominated by flame exposure of the melted urethane collected in the trough. However, greater smoke production was evident as the heat flux level was increased for nonpiloted exposure. Smoke production in general was low as compared with the other 13 materials over the range of heat fluxes tested. This may be attributed to the material being shielded from radiant heat exposure when it melted into the trough on the sample holder. Rapid melting is always observed of foams when they are tested in the NBS smoke chamber. These foams would pass the limits under some test conditions and fail, usually marginally, at others. However, the low smoking characteristic is primarily the result of rapid melting of the foam away from the high radiant heat exposure area. A more appropriate method of testing polyurethane foams, or other materials which melt, would be to use a horizontal sample holder to contain the material within the radiant heat exposure area. Breden and Meisters (reference 6) have demonstrated that D_m for thermoplastics in a horizontal test orientation can increase by a factor of approximately 3 to 8, depending on the material, over the vertical orientation results.

PANELS. Five materials were designated panels; Nos. 224, 225, 227, and 233 were of the typical honeycomb construction, while No. 234 was a molded polyester fiberglass. A bar graph (figure 8) shows the behavior of these panels in relation to a limit of $D_s \leq 100$ at 90 seconds and $D_s \leq 200$ at 4 minutes. The lowest smoke producing panel of the five tested was material No. 227, which also was by far the thinnest composite panel tested. This panel exhibited exceptionally low smoke levels for both piloted and nonpiloted exposure at all heat flux levels tested. Smoke levels at all test conditions for this panel were well within the considered limits. The remaining panels only passed the smoke limits for 2.2 Btu/ft^2 s for both piloted and nonpiloted exposure. (Panel No. 224 only passed the limits for 2.2-Btu/ft^2 s nonpiloted exposure tests.) At higher heat flux levels, these panels would readily fail the smoke performance limits.

Smoke history plots for the panels are found in appendix B (see figures B-17 through B-26). Smoke production increased monotonically with incident heat flux for both piloted and nonpiloted exposure. Most panels tested produce similar results at 7.5 and 10.0 Btu/ft^2 s. Panel No. 234 is a good example of a material displaying very low smoking tendencies at 2.2 Btu/ft^2 s but significantly greater amounts of smoke at 5.0, 7.5 and 10.0 Btu/ft^2 s. The necessity for evaluating materials at higher heat flux levels is again demonstrated by this and other panels. All panels remained intact and did not burn-through for the heat flux levels tested. Panels with a polyvinyl fluoride coating (PVF) lost this decorative finish in the first 30 seconds of testing. This resulted in a sharp rise in smoke production and then slower smoke production for the remainder of the test. The smoke was believed to be primarily due to the involvement of the resin used in the fiberglass facing and honeycomb core components of the panels. The thickness or weight of the panel also appears to have a bearing on smoke production. Material No. 227 was the thinnest and lightest honeycomb panel tested and also produced the least amount of smoke. Material No. 233 was of medium thickness and weight and was the next lowest smoking panel. Materials Nos. 224 and 225 were thicker and heavier than material No. 233 and produced greater amounts of smoke.

PLASTICS. Two types of plastic sheets were tested, No. 220, polysulfone, (figures B-27 and B-28), and No. 235, polycarbonate (figures B-29 and B-30). Both materials exhibited very low smoking characteristics at 2.2 Btu/ft^2 s for piloted and nonpiloted exposure. However, a significant increase in smoke production was observed as the heat flux level was increased. The polysulfone sample actually grew out of the holder and extended toward the furnace, producing a dense, black, sooty smoke at the higher heat fluxes. It then formed a crusty char in the shape of a bubble in the sample holder. Polycarbonate, in contrast, formed stringy drips which extended to the floor, while also producing vast amounts of black, sooty smoke at the higher heat fluxes. For these two plastics, smoke increased monotonically with increasing incident heat flux. More than any of the other materials tested, the plastics exhibited the most dramatic increases in smoke production over that at 2.2 Btu/ft^2 s, again showing the necessity for varying the heat flux exposure in materials testing.

SPECIFIC OPTICAL DENSITY COMPARISON. Four plots were constructed of D_s (piloted) versus D_s (nonpiloted) at 4 minutes for the heat flux levels tested (figure 9). Those levels where the smoke level peaked or saturated the photometer (D_s=800) before 4 minutes are not included in this comparison. The 45° line is a perfect correlation line for D_s-nonpiloted ignition versus D_s-piloted ignition. It is clear from these plots that the piloted test at 2.2 Btu/ft^2 s is a more severe test than a nonpiloted test at the same heat flux. For all 15 materials, the smoke level is greater for piloted exposure than for nonpiloted. However, as the heat flux level is increased, the nonpiloted smoke levels tend to exceed the piloted values, making the nonpiloted mode a more severe test condition. At 10 Btu/ft^2 s for most materials, a nonpiloted test is clearly more severe than a piloted test. Thus, for flame resistant aircraft cabin materials, the presence of a pilot flame ignition source caused more smoke at lower heat fluxes and less smoke at higher heat fluxes.

SPECIFIC OPTICAL DENSITY RANKING. The smoke history plots in appendix B were used for additional analysis of the data. Tables 1 and 2 of maximum specific optical density (D_m) were very easily constructed from the data in appendix B. The tables give some indication of the smoking characteristics of cabin materials, in general, as heat flux is increased. For example, the data in table 1 for nonpiloted exposure exhibit some interesting trends. At 2.2 Btu/ft^2 s, D_m for 11 of 15 materials was less than 100, and 13 of these materials had not achieved peak smoke production at the end of the test (7 minutes). In comparison, there was only one material at each higher heat flux level with D_m less than 100. Also, at the 3 higher heat flux levels, the values of D_m are particularly distributed throughout the range of measurements. As the heat flux level was increased, the time of occurence of D_m tended to decrease. At 10 Btu/ft^2 s, 13 of the materials achieved peak smoke production in less than 4 minutes. Similar trends can be gleaned from table 2 for piloted exposure.

D_s at 90 seconds and 4 minutes for nonpiloted and piloted tests, respectively, was used in arranging tables 3 and 4. These specific optical densities were arranged in increasing order, with the lowest D_s being the best material and the highest D_s being the worst material. It is evident from these tables that a material such as No. 210 polyvinyl chloride (PVC) (a coated cotton fabric) is rated very low when compared with the other materials tested.

A material such as No. 235 (a polycarbonate plastic) looks favorable when compared with other materials at 2.2 Btu/ft^2 s. However, its data becomes increasingly worse with increasing heat flux until it was among the lowest rated materials tested at the 10.0 Btu/ft^2 s level. However, the opposite is also true with a material such as No. 204 (a wool/nylon blended fabric) which tends to look more favorable with increasing heat flux for piloted exposure.

WEIGHT LOSS ANALYSIS. Instantaneous weight loss data were taken continuously for each test material. Weight loss in grams was calculated for each material at 30, 60, and 90 seconds and is presented in table 5. Based on 90-second data, in 86 percent of the tests more material is lost for piloted exposure than for nonpiloted, although in only 59 percent of the tests was more smoke produced for the piloted exposure. One material was chosen from each of the five usage categories for which time history plots of specific optical density and weight loss were constructed (figures 10 through 19). Reasonably good correlation was noted for some materials between D_s and weight loss at some heat flux levels, especially for nonpiloted exposure. There appears to be a time lag between any noticeable weight loss and an indication of increasing D_s. This is probably due to the separation of the sample holder from the photometric system within the chamber. An interesting trend for some materials (e.g., vinyl/ABS No. 230) is that D_s is approximately 100 times the weight loss in grams. Apparently, for this material the fraction of weight loss converted into smoke is fairly constant and independent of exposure conditions. However, this behavior does not exist for most materials, especially for piloted exposure tests. Based on residual weight measurements, fabrics and foams appeared to be entirely consumed at higher heat fluxes; whereas, flooring, panels, and plastics only experienced a maximum of 50-percent weight loss for the 10-minute test duration.

SUMMARY OF RESULTS

1. For most of the 15 materials tested, smoke production increased with increasing heat flux provided the sample did not ignite. This was true for both piloted and nonpiloted conditions. When ignition of the material occurred, smoke production would decrease, as observed during individual tests. Material Nos. 210, 226, 230, and 235 were exceptions to this behavior.

2. Polycarbonate and polysulfone sheets exhibited the most significant differences in smoke production between 2.2 Btu/ft^2 s (the "standard" exposure condition) and higher heat fluxes. These materials produce very low smoke in both piloted and nonpiloted exposure tests at 2.2 Btu/ft^2 s, but at 7.5 and 10.0 Btu/ft^2 s they emitted as much smoke as the smokiest materials tested.

3. Wool carpet and vinyl/ABS flooring produced considerably more smoke at heat flux levels above the standard 2.2-Btu/ft^2 s value.

4. The smoke production of foams and fabrics did not change appreciably over the range of heat fluxes tested.

5. A vertically-oriented laser transmissometer often produced very low light transmittance data because of soot particles deposited on the bottom window that blocked the narrow laser beam. The standard photometric system has a much wider light beam and an electrical heater for reducing deposition which greatly diminishes the susceptibility to this problem.

6. Some materials exhibited a correspondence between the D_s and weight loss histories (e.g., vinyl/ABS flooring); however, this similarity was not evident for most materials, especially under piloted exposure conditions.

7. For the composite panels, smoke production increased monotonically with incident heat flux for both piloted and nonpiloted exposure. The thinnest of these panels had low smoke emissions at all test conditions.

CONCLUSIONS

1. The modified NBS smoke chamber, as equipped with a new variable radiant heater is a valuable test protocol for measuring smoke density of an aircraft cabin material for a range of heat flux levels.

2. The magnitude of radiant heat flux and the type of ignition have a major influence on the smoke emission characteristics of aircraft interior materials.

3. The standard 2.2-Btu/ft^2 s heat flux is insufficient for evaluating the smoke characteristics of cabin materials in a postcrash cabin fire situation where a higher and wider range of heat flux levels exist.

REFERENCES

1. Standard Test Method for Smoke Generated by Solid Materials, National Fire Protection Association, NFPA 258, Boston, Massachusetts, 1976.

2. Sarkos, Constantine P., Measurement of Toxic Gases and Smoke from Aircraft Cabin Interior Materials Using the NBS Smoke Chamber and Calorimetric Tubes, FAA-RD-76-7, March 1976.

3. Gaskill, James R. et al., Development, Calibration, and Use of a High-Flux Heater in the NBS/LLL Smoke Chamber, Journal of Fire and Flammability, Vol. 8, April 1977.

4. Aircraft: Civil and Military, Fire Safety Aspects of Polymeric Materials, A report by National Materials Advisory Board, National Academy of Sciences, NMAB 318-6, Volume 6, 1977.

5. Smoke Emission from Compartment Interior Materials, DOT/FAA/FSS, Transport Category Airplanes, Federal Register, Vol. 40, pg. 6,505, February 12, 1975.

6. Breden, L. and Meisters, M., The Effect of Sample Orientation in the Smoke Density Chamber, Journal of Fire and Flammability, Vol. 7, pgs. 234-247, April 1976.

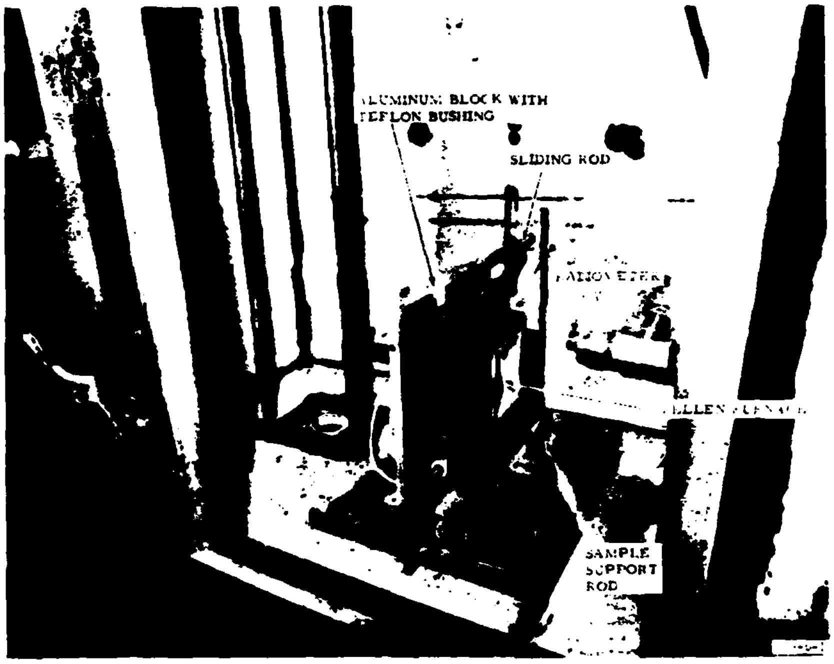

FIGURE 1.   SLIDER MECHANISM FOR MELLEN FURNACE (INSIDE VIEW)

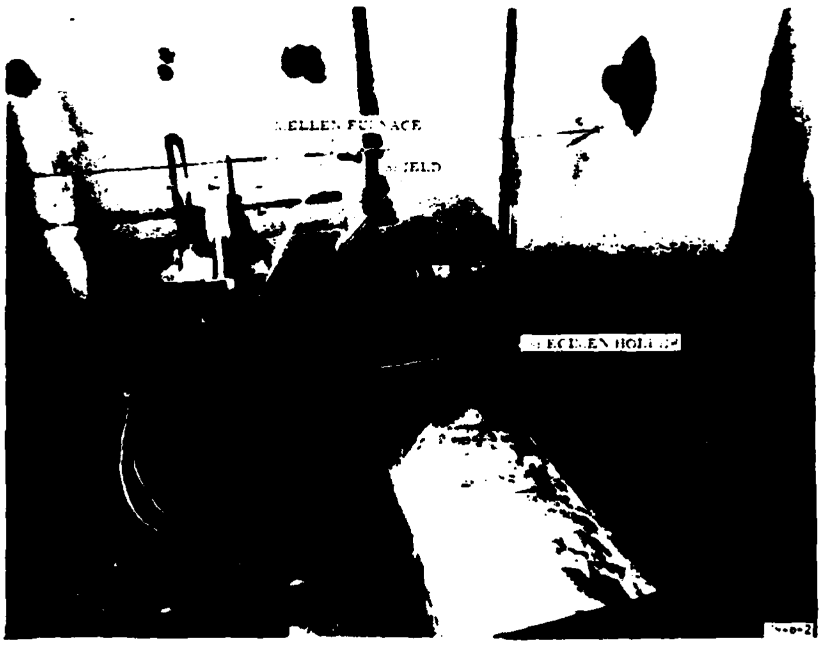

FIGURE 2. MELLEN FURNACE IN CALIBRATE POSITION

FIGURE 3. MELLEN FURNACE IN TEST POSITION

FIGURE 4. SLIDER MECHANISM (OUTSIDE VIEW)

FIGURE 5. SHIELD--PULLEY SYSTEM

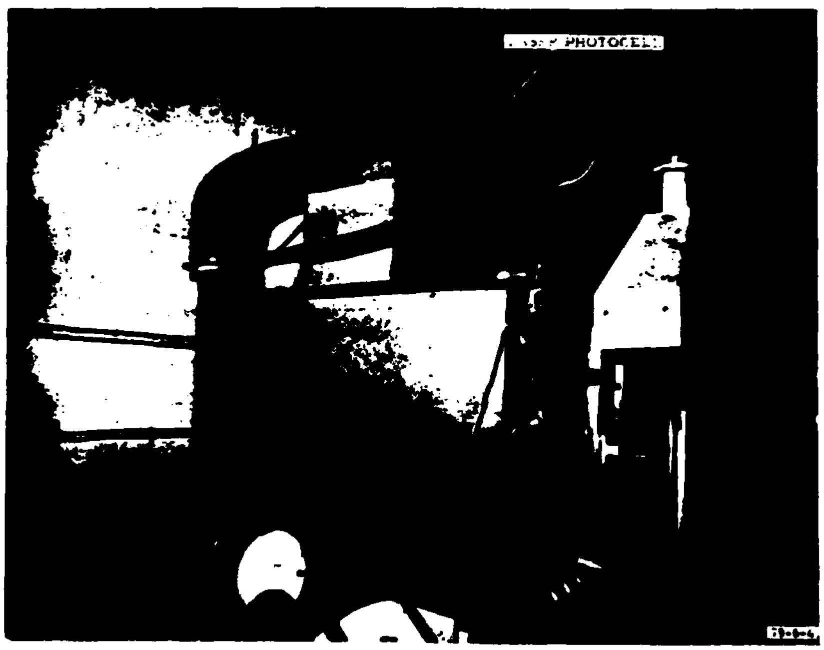

FIGURE 6. LASER PHOTOCELL ON TOP OF SMOKE CHAMBER

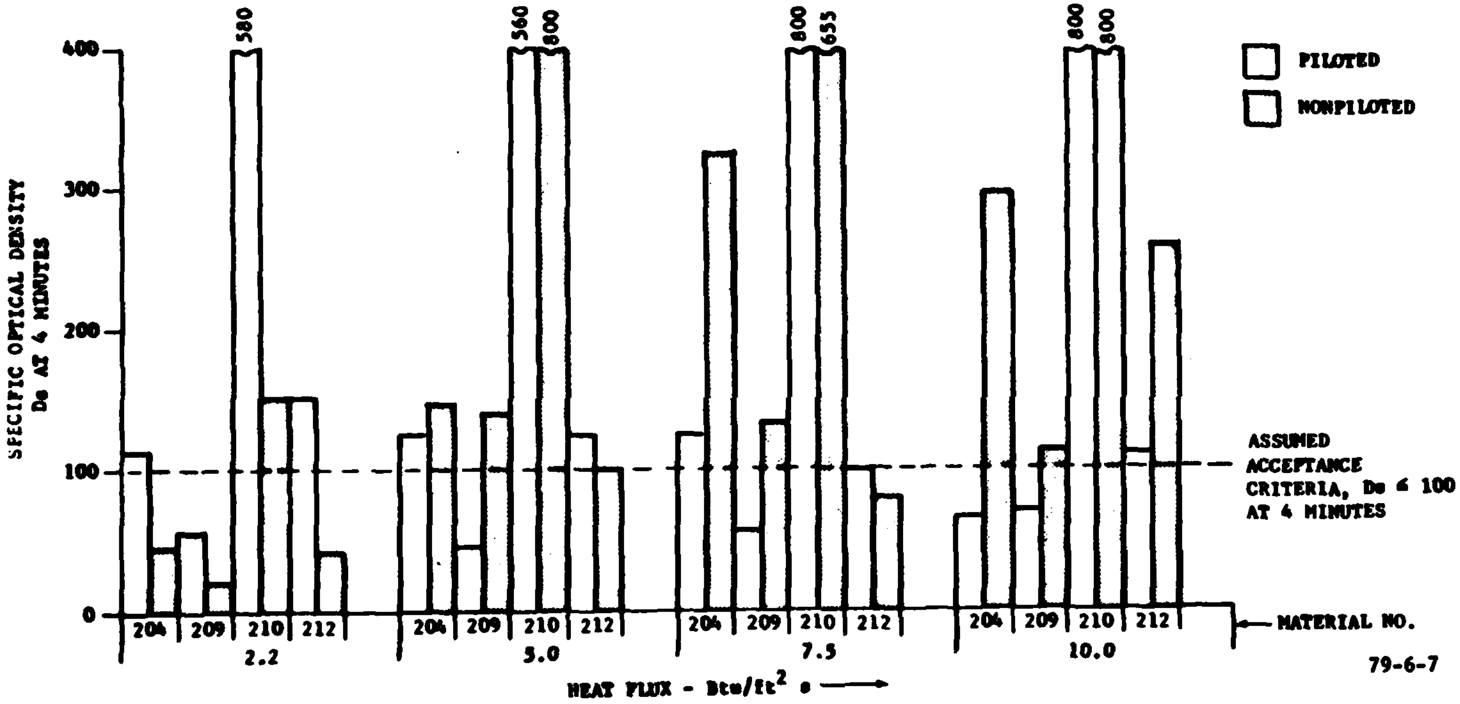

FIGURE 7. SMOKE DENSITY OF FABRICS

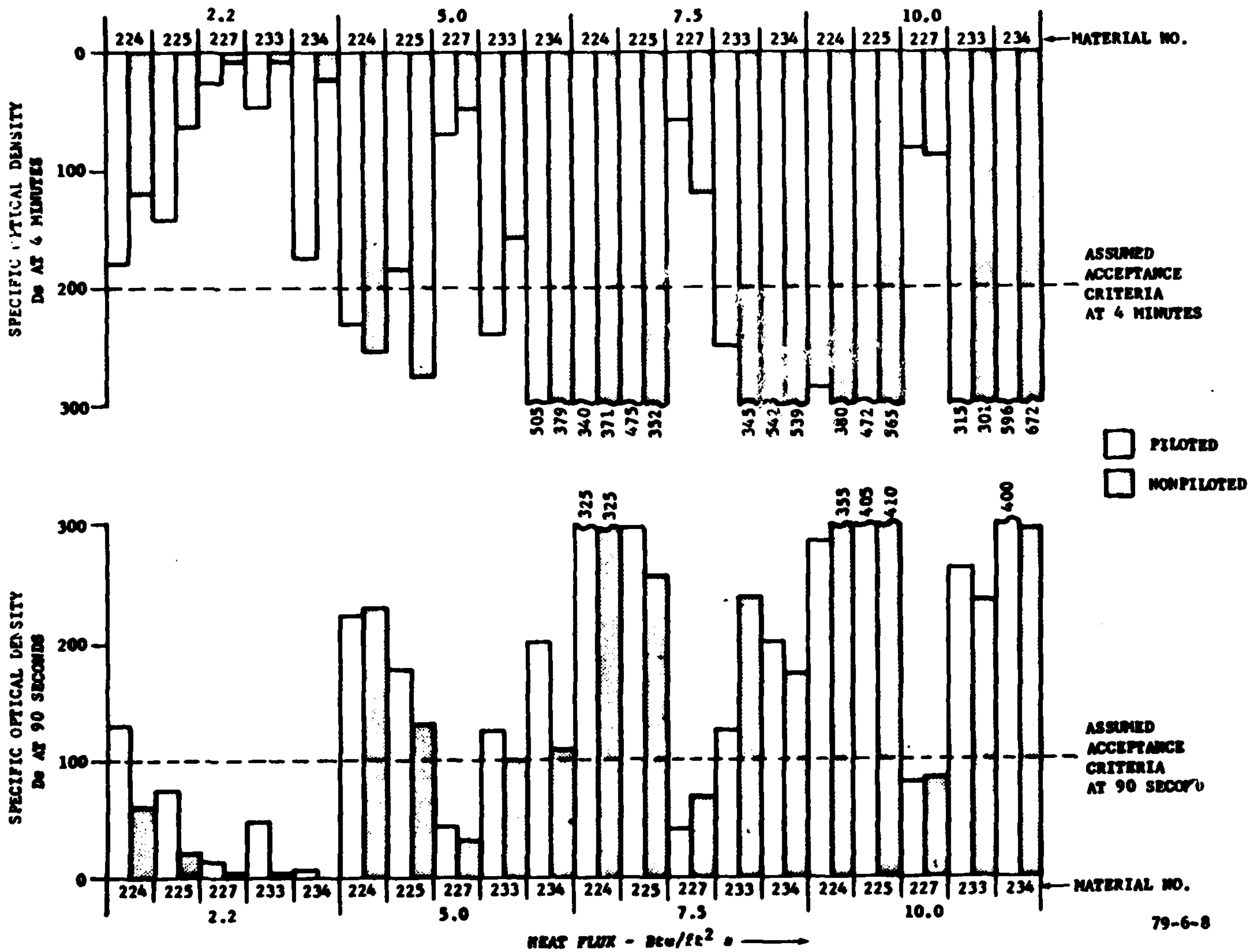

FIGURE 8. SMOKE DENSITY OF PANELS

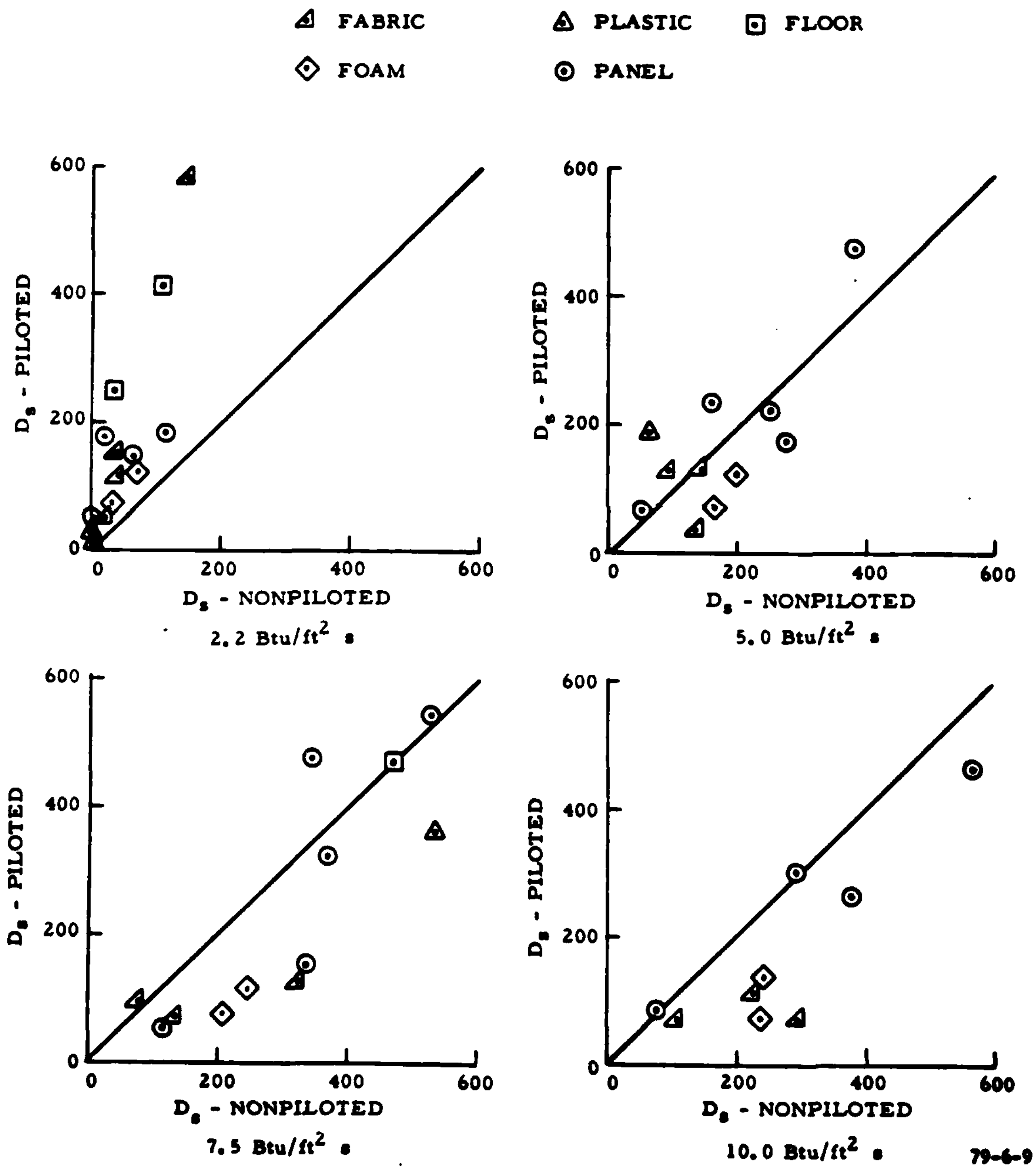

FIGURE 9. D_s (PILOTED) VERSUS D_s (NONPILOTED) AT 4 MINUTES

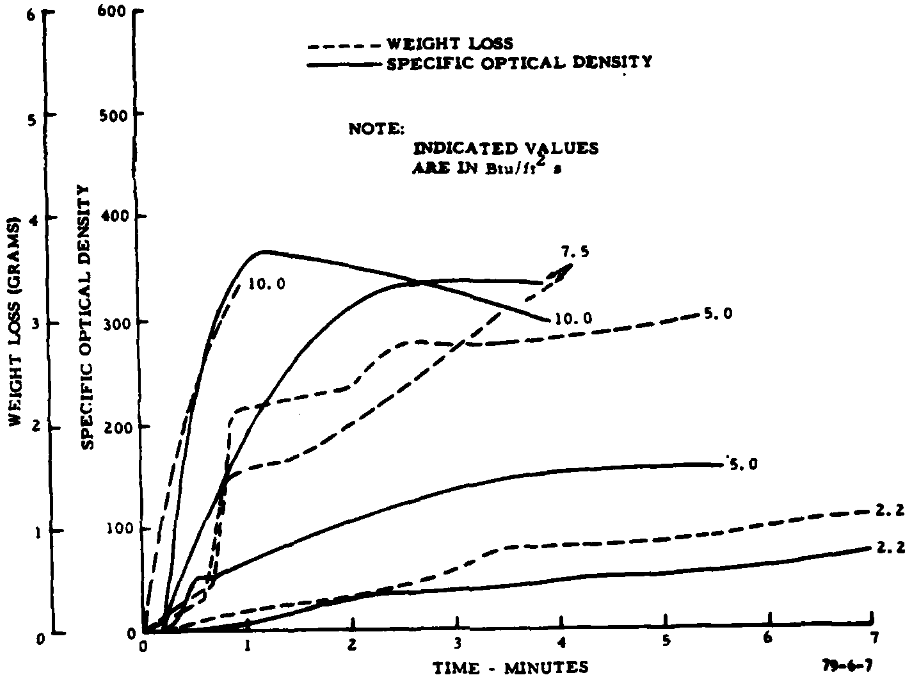

FIGURE 10. SPECIFIC OPTICAL DENSITY (D_S) VERSUS WEIGHT LOSS NO. 204 (FABRIC--NONPILOTED)

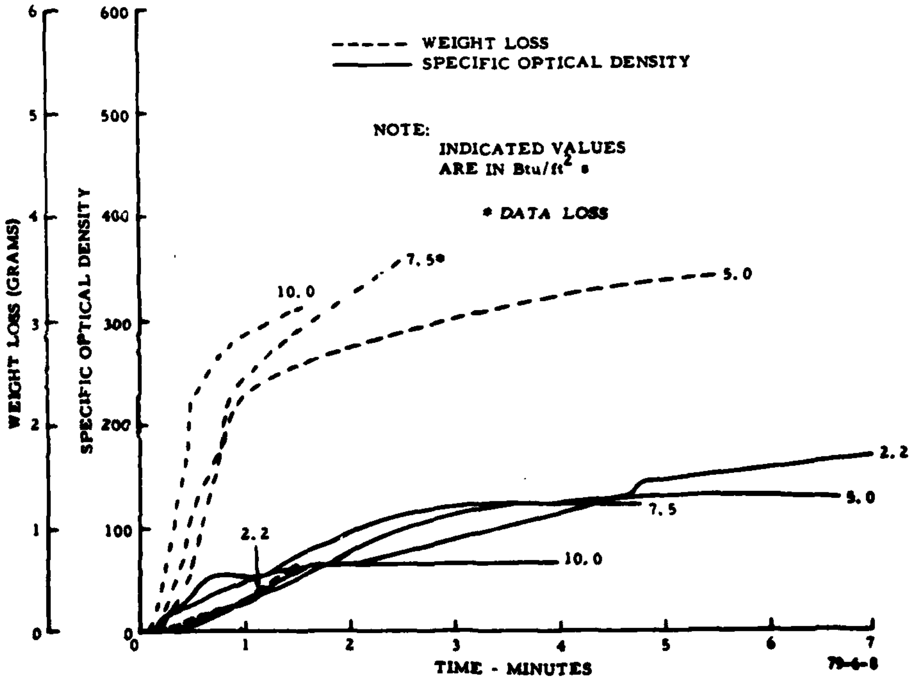

FIGURE 11. SPECIFIC OPTICAL DENSITY (D_S) VERSUS WEIGHT LOSS NO. 204 (FABRIC--PILOTED)

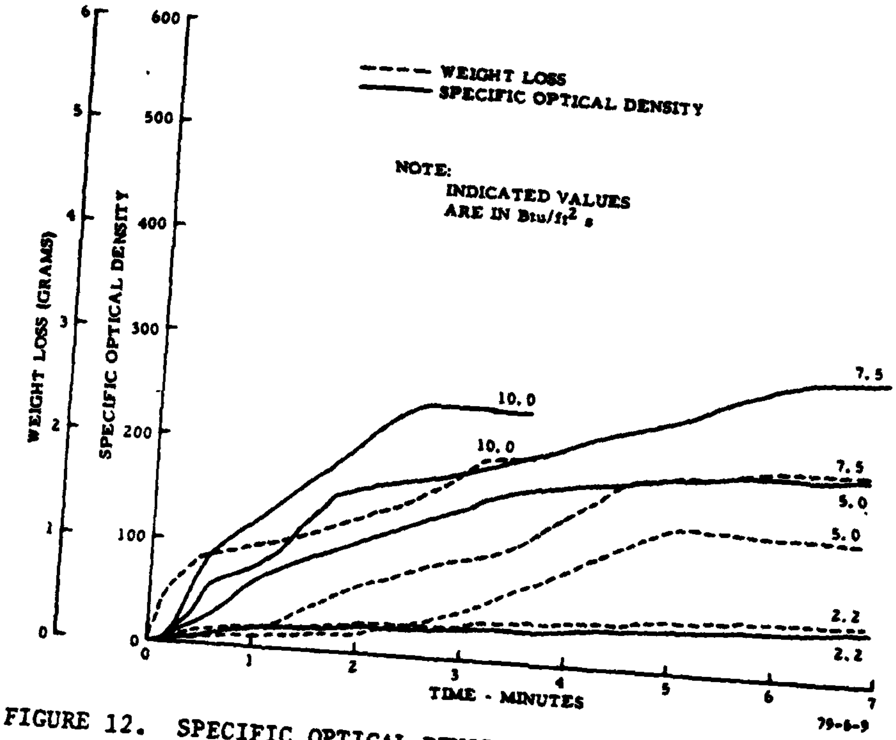

FIGURE 12. SPECIFIC OPTICAL DENSITY (D_s) VERSUS WEIGHT LOSS NO. 215 (FOAM--NONPILOTED)

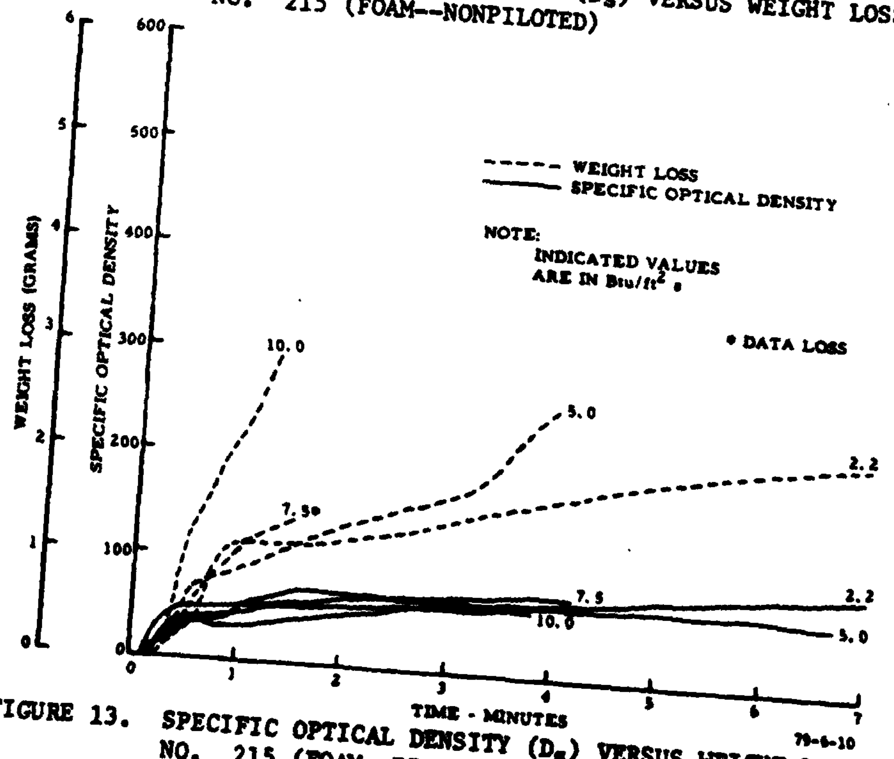

FIGURE 13. SPECIFIC OPTICAL DENSITY (D_s) VERSUS WEIGHT LOSS NO. 215 (FOAM--PILOTED)

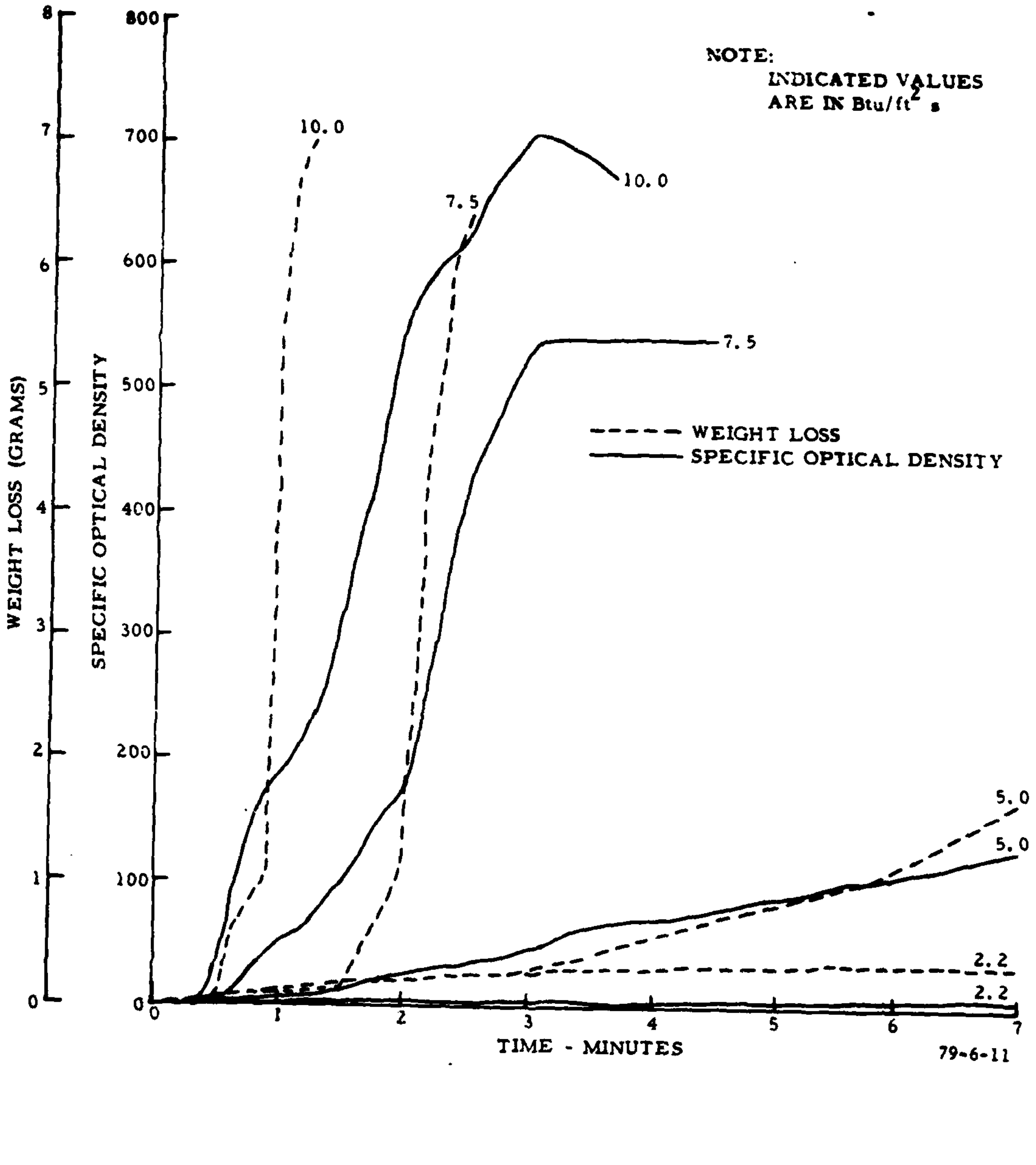

FIGURE 14. SPECIFIC OPTICAL DENSITY (D_s) VERSUS WEIGHT LOSS NO. 220 (PLASTIC--NONPILOTED)

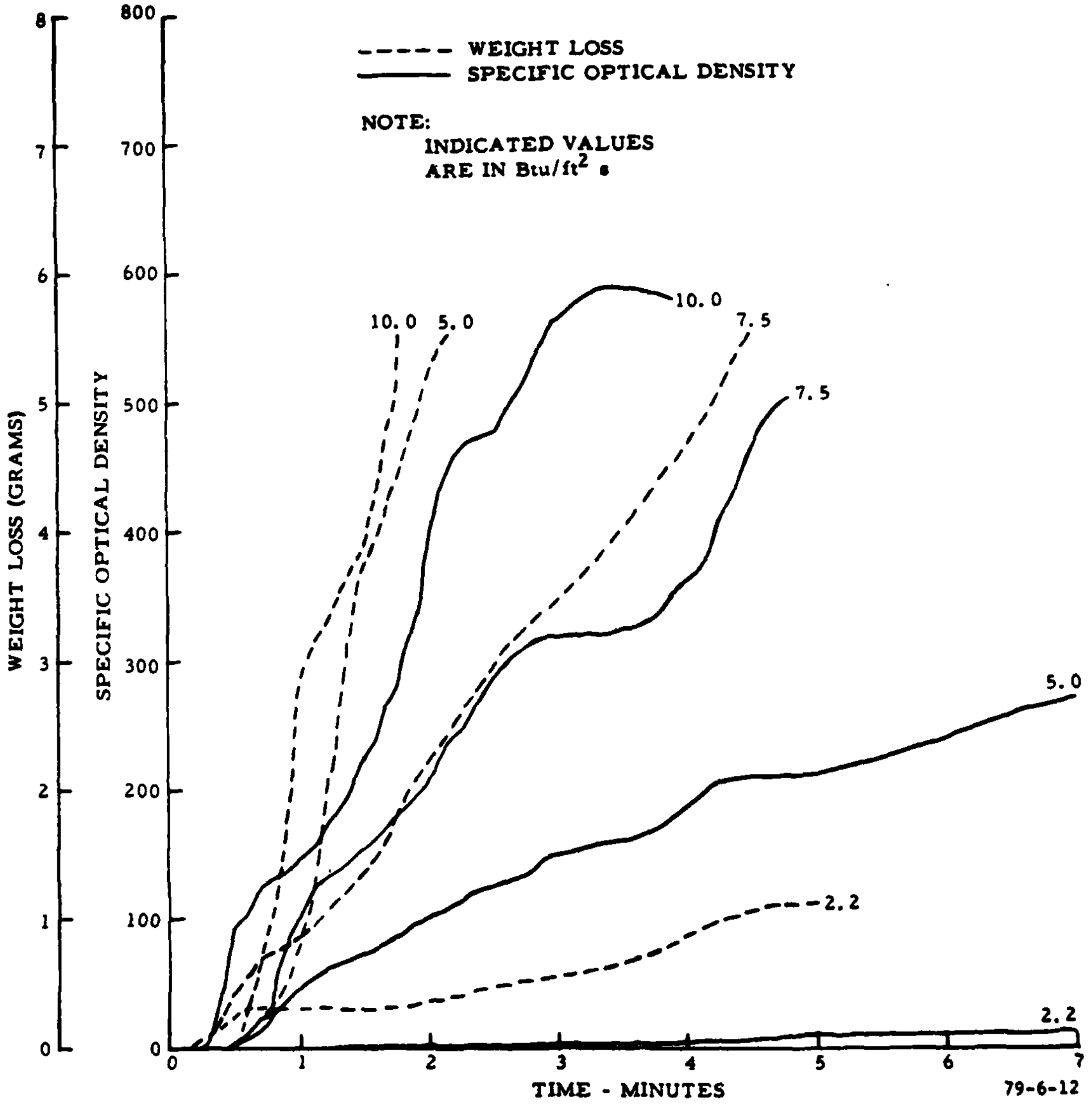

FIGURE 15. SPECIFIC OPTICAL DENSITY (D_s) VERSUS WEIGHT LOSS
NO. 220 (PLASTIC--PILOTED)

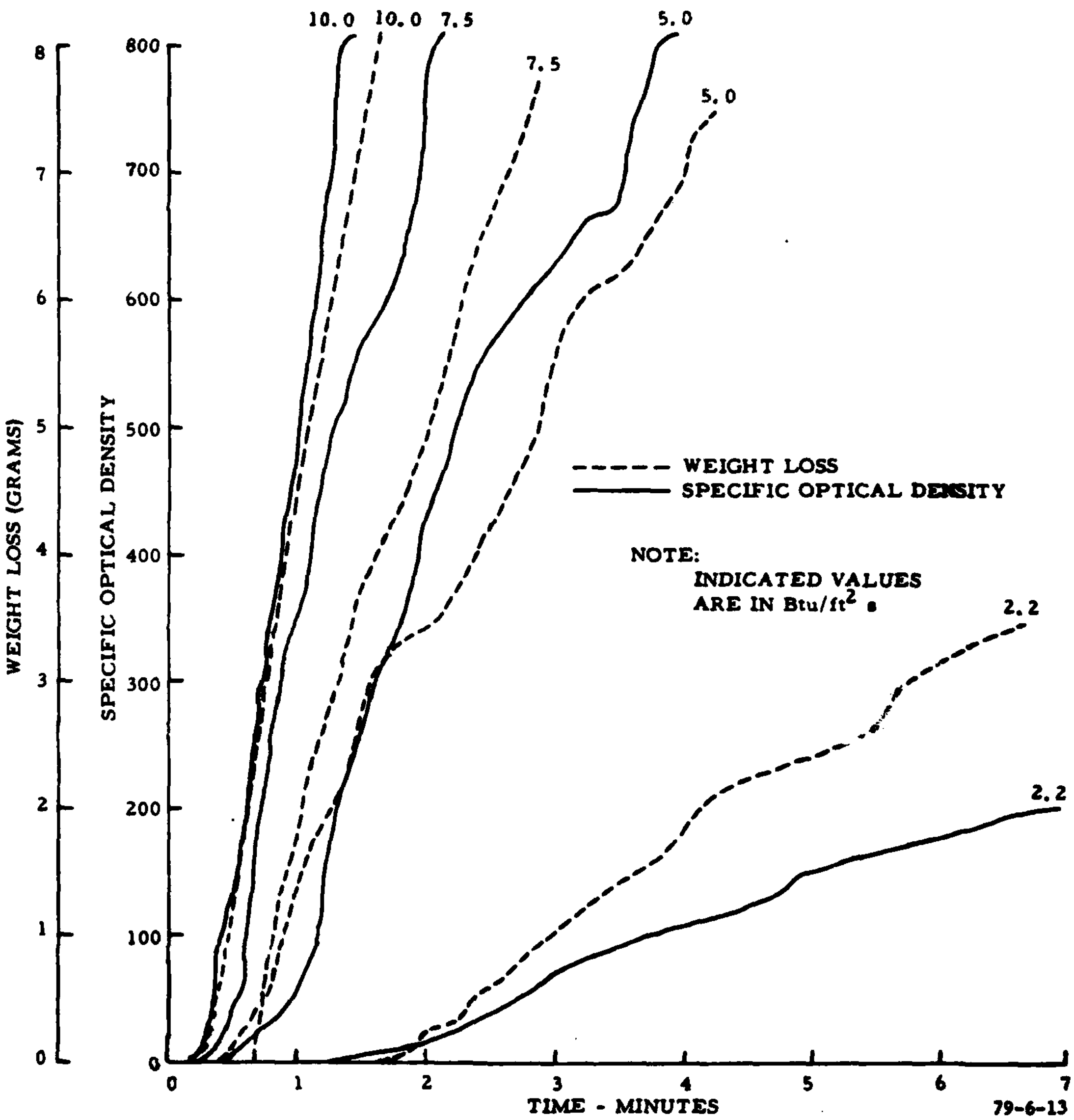

FIGURE 16. SPECIFIC OPTICAL DENSITY (D_s) VERSUS WEIGHT LOSS NO. 230 (FLOORING--NONPILOTED)

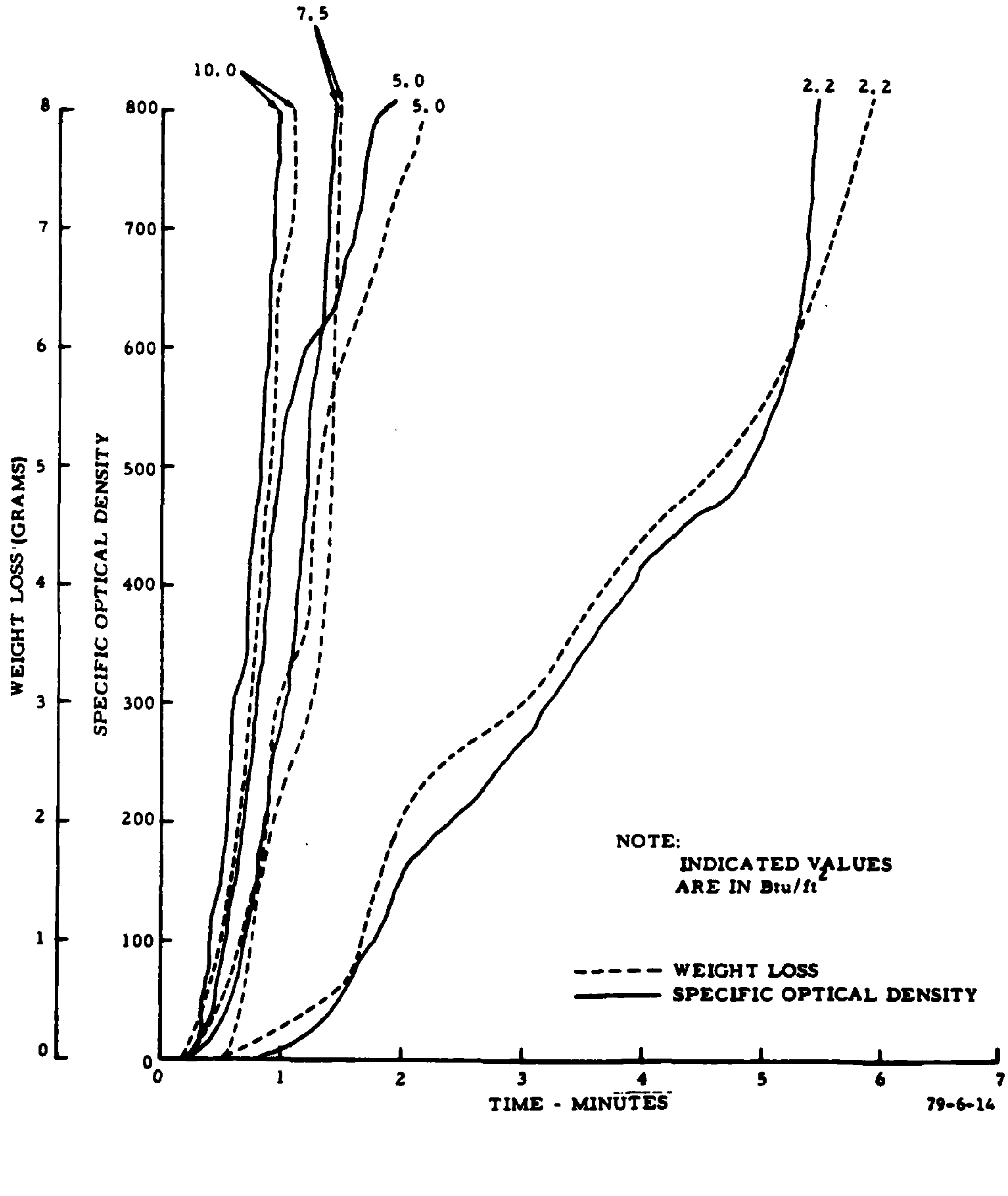

FIGURE 17. SPECIFIC OPTICAL DENSITY (D_s) VERSUS WEIGHT LOSS NO. 230 (FLOORING—PILOTED)

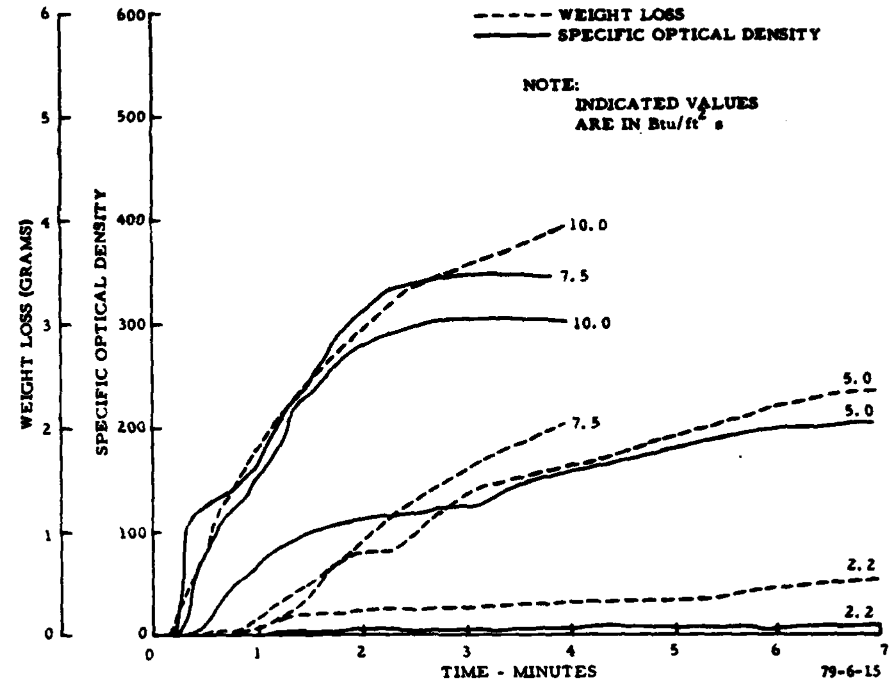

FIGURE 18. SPECIFIC OPTICAL DENSITY VERSUS WEIGHT LOSS NO. 233 (PANEL--NONPILOTED)

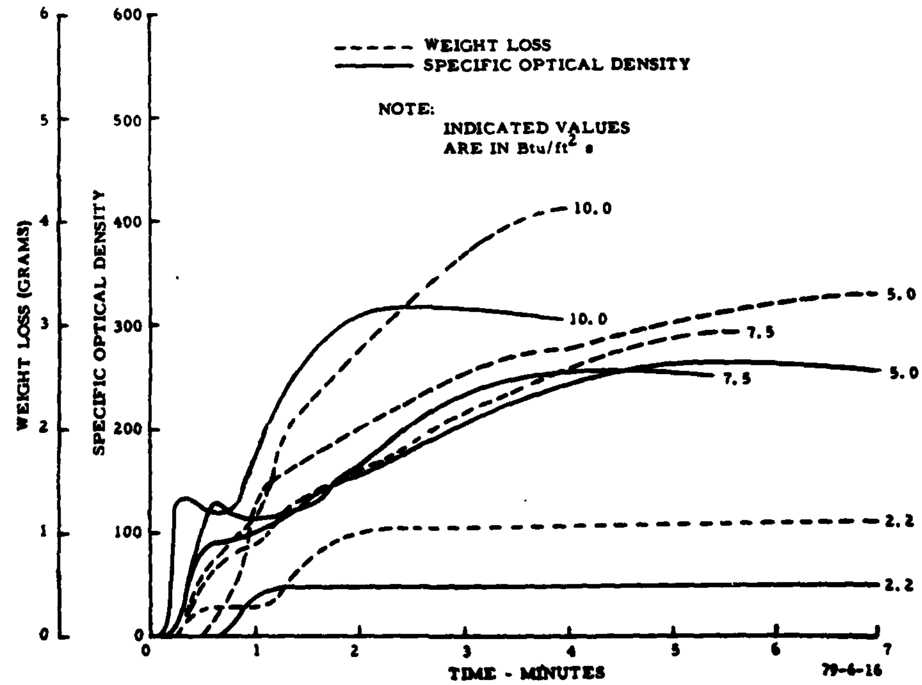

FIGURE 19. SPECIFIC OPTICAL DENSITY (D_s) VERSUS WEIGHT LOSS NO. 233 (PANEL--PILOTED)

TABLE 1. MAXIMUM SPECIFIC OPTICAL DENSITY (D_m) (NONPILOTED EXPOSURE)

* No.	2.2 (Btu/ft^2 s) D_m	Time (min)	5.0 (Btu/ft^2 s) D_m	Time (min)	7.5 (Btu/ft^2 s) D_m	Time (min)	10.0 Btu/ft^2 s) D_m	Time (min)
204	69	7+	153	5.4	230	3.0	360	1.3
209	29	7+	151	6.2	160	6.2	115	5
210	250	7+	803	1.7	664	1.5	803	0.95
212	50	6.5	11[illegible]	5.8	80	3.7	260	1.8
213	115	7+	215	5.5	258	5.5	250	2.4
215	2	7+	198	7+	289	7+	241	2.6
220	4	7+	129	7+	536	3.1	700	3
224	138	7+	255	2.5	375	4.5	380	3.7
225	80	7+	390	7+	420	6.6	567	4.5
226	90	7+	803	3.5	480	3.6	603	2
227	11	7+	67	7+	125	4.4	89	3.2
230	200	7+	803	3.9	803	2.1	803	1.5
233	10	6.5	202	6.9	346	3	302	3.3
234	63	7+	461	6.6	549	4.3	672	3.8
235	0	7+	212	7+	513	6	803	1.4

* See Appendix A for material description

TABLE 2. MAXIMUM SPECIFIC OPTICAL DENSITY (D_m) (PILOTED EXPOSURE)

* No.	2.2 (Btu/ft^2 s) D_m	Time (min)	5.0 (Btu/ft^2 s) D_m	Time (min)	7.5 (Btu/ft^2 s) D_m	Time (min)	10.0 (Btu/ft^2 s) D_m	Time (min)
204	167	7+	128	4.5	123	3.7	65	2.1
209	70	7+	58	7+	72	7+	76	4.8
210	592	3	592	1.8	803	1.1	803	1.2
212	170	6.7	124	4.2	100	4.6	111	3.2
213	129	7+	116	3.5	115	2.7	135	1.8
215	94	7+	70	4.6	76	3.7	66	2.3
220	12	7+	268	7+	500	4.8	583	3.8
224	130	4.2	240	2.8	340	2.2	284	0.6
225	145	4.3	194	2.5	480	4.3	473	4.3
226	803	7+	446	4.6	471	3.8	540	2.7
227	35	7+	89	7+	70	7+	84	3.1
230	803	5.5	803	2	803	1.45	803	1
233	48	1.3	259	1.5	252	4.3	315	2.5
234	450	7+	505	2.8	556	4.7	596	2.9
235	143	7+	803	2.7	803	1.7	803	1.2

* See Appendix A for material description

TABLE 3. MATERIAL RANKING BY SPECIFIC OPTICAL DENSITY (D_s) (NONPILOTED EXPOSURE)

90 s	2.2 (Btu/ft² s)	5.0 (Btu/ft² s)	7.5 (Btu/ft² s)	10.0 (Btu/ft² s)	4 min	2.2 (Btu/ft² s)	5.0 (Btu/ft² s)	7.5 (Btu/ft² s)	10.0 (Btu/ft² s)
Lowest Density	235*	220	235	227	Lowest Density	235	227	212	227
	236	235	212	209		220	220	227	209
	220	227	227	215		233	212	209	212
	227	209	209	213		227	235	215	215
	230	213	220	233		209	209	213	213
	233	206	215	212		236	206	204	204
	209	215	226	235		215	233	233	233
	212	233	236	220		226	215	225	224
	206	236	213	224		212	213	224	225
	226	226	233	206		206	224	226	220
	225	225	206	225		225	225	235	234
	210	213	225	226		213	236	220	226
	215	224	224	210		230	230	236	235
	213	230	230	234		224	226	230	230
Highest Density	224	210	210	230	Highest Density	210	210	210	210

* See Appendix A for material description

TABLE 4. MATERIAL RANKING BY SPECIFIC OPTICAL DENSITY (D_s) (PILOTED EXPOSURE)

90 s	2.2 (Btu/ft² s)	5.0 (Btu/ft² s)	7.5 (Btu/ft² s)	10.0 (Btu/ft² s)	4 min	2.2 (Btu/ft² s)	5.0 (Btu/ft² s)	7.5 (Btu/ft² s)	10.0 (Btu/ft² s)
Lowest Density	235 *	209	209	209	Lowest Density	220	209	227	204
↓	220	215	227	215	↓	235	215	209	209
	234	227	212	204		227	227	215	215
	227	204	215	212		233	213	212	227
	209	226	204	227		209	204	213	212
	226	220	213	213		215	212	204	213
	233	212	233	220		204	225	233	224
	230	235	226	226		213	220	224	233
	215	213	220	233		225	224	220	225
	204	233	234	224		212	233	226	226
	212	225	225	234		234	226	225	234
	225	234	224	225		224	234	234	220
	213	224	235	235		226	210	235	235
↓	224	210	230	230	↓	230	235	230	230
Highest Density	210	230	210	210	Highest Density	210	230	210	210

* See Appendix A for material description

TABLE 5. WEIGHT LOSS VERSUS INCREASING HEAT FLUX

Piloted						Nonpiloted					
* No.	Btu/ft^2s	Initial Weight (g)	Weight Loss (g) for 30 s	Weight Loss (g) for 60 s	Weight Loss (g) for 90 s	No.	Btu/ft^2s	Initial Weight (g)	Weight Loss (g) for 30 s	Weight Loss (g) for 60 s	Weight Loss (g) for 90 s
204	2.2	3.49	0.14	0.28	0.60	204	2.2	3.25	0.05	0.2	0.25
	5.0	3.45	1.12	2.24	2.52		5.0	3.54	0.32	2.10	2.21
	7.5	3.89	0.66	2.42	2.86		7.5	3.49	0.27	1.55	1.65
	10.0	3.30	2.20	—	--		10.0	3.46	2.20	3.30	—
209	2.2	3.28	0.28	0.56	0.84	209	2.2	3.10	0	0	0.28
	5.0	3.13	0	0.73	1.40		5.0	3.22	0	0.55	0.55
	7.5	3.15	0.88	1.32	1.76		7.5	3.27	0	0.55	1.10
	10.0	3.06	0.55	1.65	1.65		10.0	3.18	1.93	2.59	2.59
210	2.2	6.92	0.28	0.56	1.68	210	2.2	6.75	0	0	1.40
	5.0	6.87	0.70	3.36	5.04		5.0	6.84	0	1.93	2.75
	7.5	6.86	0.88	4.40	—		7.5	6.99	0	3.85	5.23
	10.0	6.93	2.75	5.50	6.60		10.0	7.02	3.58	6.60	—
212	2.2	2.85	0.14	0.28	0.84	212	2.2	2.90	0	0.14	0.28
	5.0	2.79	0	0.56	0.70		5.0	3.18	0	0.83	1.10
	7.5	2.79	0.88	1.76	2.20		7.5	2.95	0.55	1.65	2.04
	10.0	3.00	1.10	2.75	--		10.0	2.79	1.10	1.65	2.20
213	2.2	3.03	0.28	1.12	1.12	213	2.2	3.15	0	0	0.14
	5.0	3.07	0.70	1.40	1.40		5.0	3.36	0	0.28	1.10
	7.5	3.06	0.88	1.32	1.76		7.5	3.14	0.55	1.10	1.10
	10.0	3.17	1.10	2.20	2.75		10.0	3.18	0.83	1.38	1.54

* See Appendix A for material description

TABLE 5. WEIGHT LOSS VERSUS INCREASING HEAT FLUX (Continued)

		Piloted						Nonpiloted			
No.	Btu/ft^{2}s	Initial Weight (g)	Weight Loss (g) for 30 s	Weight Loss (g) for 60 s	Weight Loss (g) for 90 s	No.	Btu/ft^{2}s	Initial Weight (g)	Weight Loss (g) for 30 s	Weight Loss (g) for 60 s	Weight Loss (g) for 90 s
215	2.2	2.83	0.28	1.12	1.12	215	2.2	3.25	0.13	0.17	0.21
	5.0	0.56	0.84	1.12	1.12		5.0	3.36	0.05	0.10	0.13
	7.5	3.00	0.44	1.06	1.32		7.5	3.43	0.05	0.10	0.40
	10.0	3.10	1.10	2.20	--		10.0	2.91	0.82	0.96	1.10
220	2.2	10.85	0.28	0.28	0.28	220	2.2	11.75	0.04	0.08	0.12
	5.0	11.37	0	0.84	3.64		5.0	10.87	0.04	0.10	0.14
	7.5	11.11	0.44	0.88	1.32		7.5	10.74	0.05	0.08	0.10
	10.0	10.64	0	2.75	3.85		10.0	10.72	0.4	5.50	—
224	2.2	13.92	0.28	1.12	1.18	224	2.2	13.75	0	0.14	0.42
	5.0	13.93	0.28	1.68	2.24		5.0	13.53	0	0.83	0.83
	7.5	13.84	0.88	1.54	1.76		7.5	13.59	0	1.65	1.93
	10.0	13.50	2.20	3.02	3.30		10.0	14.13	1.65	2.75	6.05
225	2.2	15.96	0	0.28	0.84	225	2.2	15.95	0	0	0.28
	5.0	16.21	0.28	1.12	1.40		5.0	16.01	0.55	0	1.10
	7.5	16.03	0.44	2.20	2.86		7.5	16.17	0.55	1.10	1.65
	10.0	16.03	1.38	3.30	3.85		10.0	16.20	1.10	2.20	3.30
226	2.2	13.79	0.14	0.28	0.70	226	2.2	13.45	0	0	0.14
	5.0	13.30	0.28	1.46	2.66		5.0	13.60	0.28	0.83	1.65
	7.5	14.07	1.76	2.64	3.96		7.5	13.84	0	0.83	2.20
	10.0	13.60	2.20	4.40	7.15		10.0	14.46	0.55	2.20	3.85

TABLE 5. WEIGHT LOSS VERSUS INCREASING HEAT FLUX (Continued)

		Piloted						Nonpiloted			
No.	Btu/ft^2s	Initial Weight (g)	Weight Loss (g) for 30 s	Weight Loss (g) for 60 s	Weight Loss (g) for 90 s	No.	Btu/ft^2s	Initial Weight (g)	Weight Loss (g) for 30 s	Weight Loss (g) for 60 s	Weight Loss (g) for 90 s
227	2.2	9.41	0	0.28	0.28	227	2.2	8.00	0	0	0.14
	5.0	8.28	0.56	0.73	1.40		5.0	10.98	1.65	2.20	3.03
	7.5	8.41	0.88	1.76	2.64		7.5	9.55	0	0.55	0.55
	10.0	8.56	1.65	2.75	3.30		10.0	8.61	1.38	2.20	2.20
230	2.2	17.15	0	0.28	0.56	230	2.2	17.10	0	0	0
	5.0	17.50	0	3.08	5.88		5.0	16.46	0	1.30	2.65
	7.5	16.68	0.44	2.20	8.80		7.5	17.29	0	1.65	3.70
	10.0	16.72	1.10	6.60	--		10.0	16.71	1.20	4.50	7.20
233	2.2	9.07	0.28	0.28	0.70	233	2.2	8.75	0	0.04	0.20
	5.0	9.24	0	1.26	1.68		5.0	8.91	0	0.04	0.40
	7.5	9.01	0.44	0.88	1.32		7.5	8.95	0	0.50	0.50
	10.0	8.96	0.55	1.10	2.20		10.0	9.08	0.83	1.80	2.42
234	2.2	15.06	0	0	0	234	2.2	15.05	0	0	0
	5.0	15.77	0	0.56	2.10		5.0	15.13	0	0	0.55
	7.5	15.16	0	0.44	1.32		7.5	14.91	0	0	0.83
	10.0	15.07	1.10	2.20	4.68		10.0	16.77	0	1.38	3.30
235	2.2	12.91	0	0	0.28	235	2.2	13.00	0	0	0
	5.0	13.20	0	0	0.28		5.0	13.32	1.10	1.65	1.65
	7.5	13.43	0	0	4.18		7.5	13.42	0	0	0.83
	10.0	13.35	0	3.58	--		10.0	12.78	0	2.20	--

-- Not available

APPENDIX A

LIST OF MATERIALS TESTED

APPENDIX A

MATERIAL LIST

Material No.	Chemical Composition*	Thickness (in)	Unit Weight (oz/yd2)	Designation	Cabin Use
20[illegible]	Wool (90%)/Nylon (10%)	0.052	16.6	Fabric	Seat Cover and Drapery
20[illegible]	FR Treated Nylon	0.052	16.2	Fabric	Seat Cover
210	PVC/Cotton (Naugafoam)® **	0.044	36.2	Fabric	Seat Backrest
21[illegible]	Wool (100%)	0.040	14.8	Fabric	Seat Cover
213	FR Urethane	0.500	15.2	Foam	Seat Cushion
215	FR Urethane	0.500	15.0	Foam	Seat Cushion
220	Polysulfone Sheet	0.069	62.5	Plastic	Thermoformed Parts
22[illegible]	PVF/fiberglass-phenolic/ Nomex® Paper-phenolic *** honeycomb fiberglass batt/fiberglass-phenolic	0.503	78.9	Panel	Ceiling
225	PVF/fiberglass-phenolic/ Nomex Paper-phenolic honeycomb/fiberglass phenolic	0.505	89.9	Panel	Overhead Stowage
226	Wool Carpet	0.250	74.0	Flooring	Passenger Compartment
227	PVF/fiberglass-phenolic/ Nomex phenolix/fiber-glass phenolic	0.087	46.8	Panel	Sidewall
230	Vinyl over ABS Laminate	0.080	95.4	Flooring	Service and Lavatory area
233	PVF/Fiberglass-Epoxy/ Nomex Honeycomb/fiber-glass epoxy	0.380	56.5	Panel	Sidewall
234	Polyester Fiberglass Molding Compound	0.080	101	Panel	Ceiling
235	Polycarbonate	0.083	78.6	Plastic	Thermoformed Parts

* Provided by Supplier

** Uniroyal Trade Name

*** DuPont Trade Name

APPENDIX B

SPECIFIC OPTICAL DENSITY VERSUS HEAT FLUX TIME HISTORY PLOTS OF TEST MATERIALS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

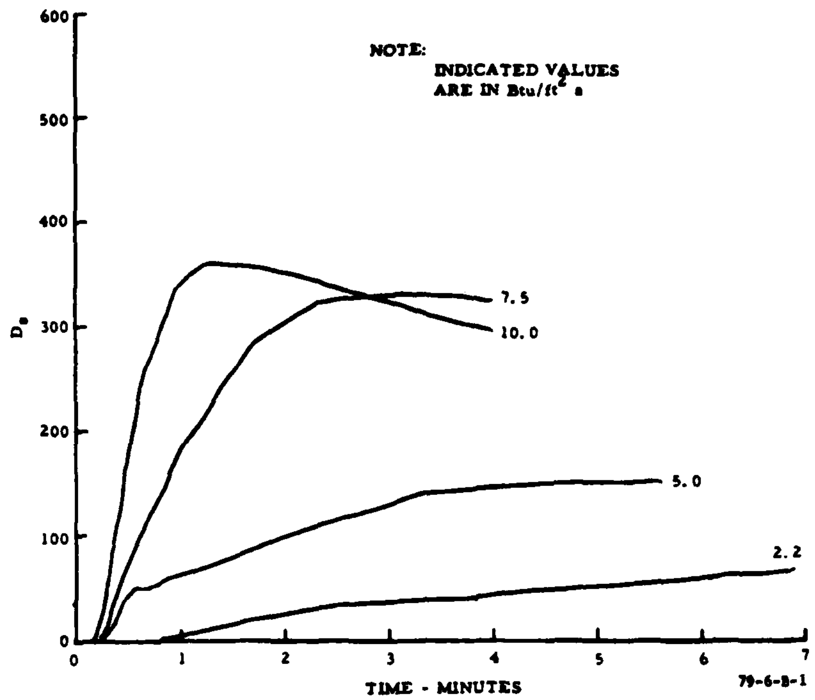

FIGURE B-1. WOOL/NYLON 90/10% (No. 204), NONPILOTED

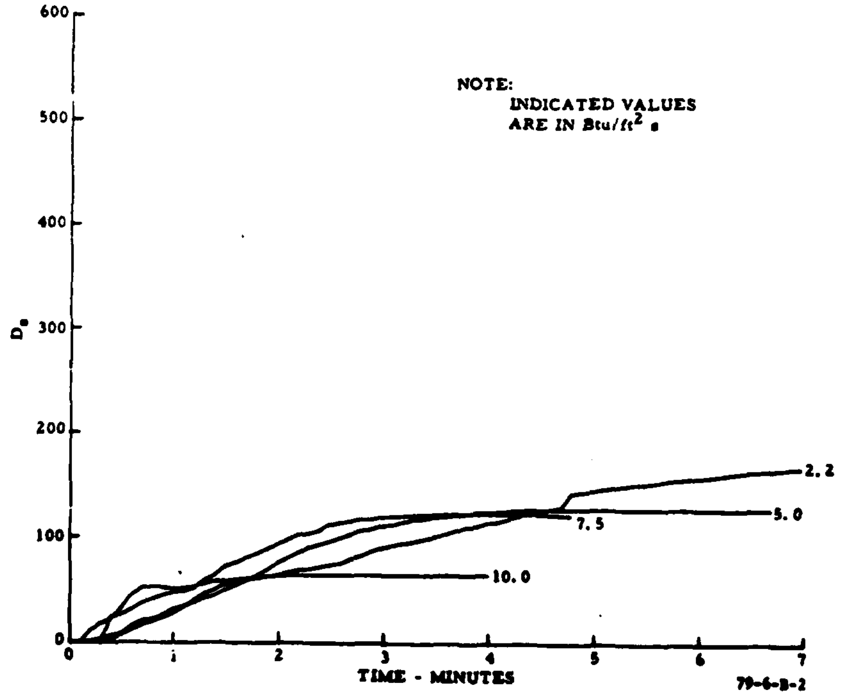

FIGURE B-2. WOOL/NYLON 90/10% (No. 204), PILOTED

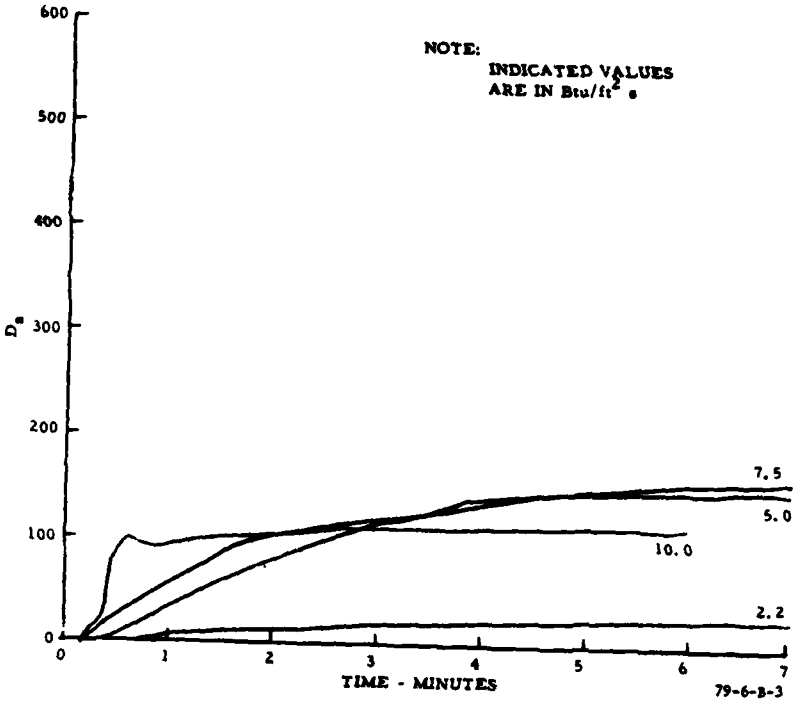

FIGURE B-3. FR TREATED NYLON (No. 209), NONPILOTED

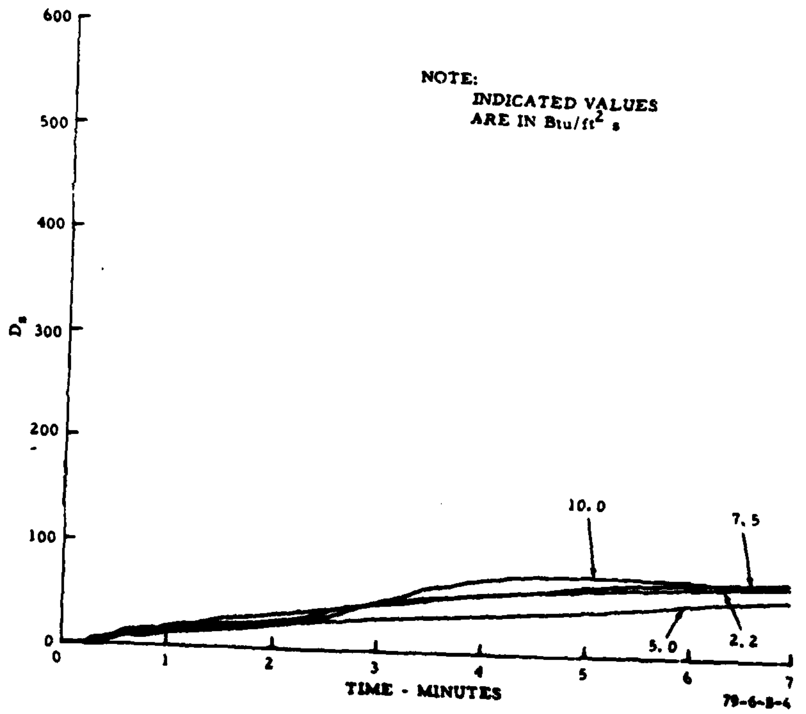

FIGURE B-4. FR TREATED NYLON (No. 209), PILOTED

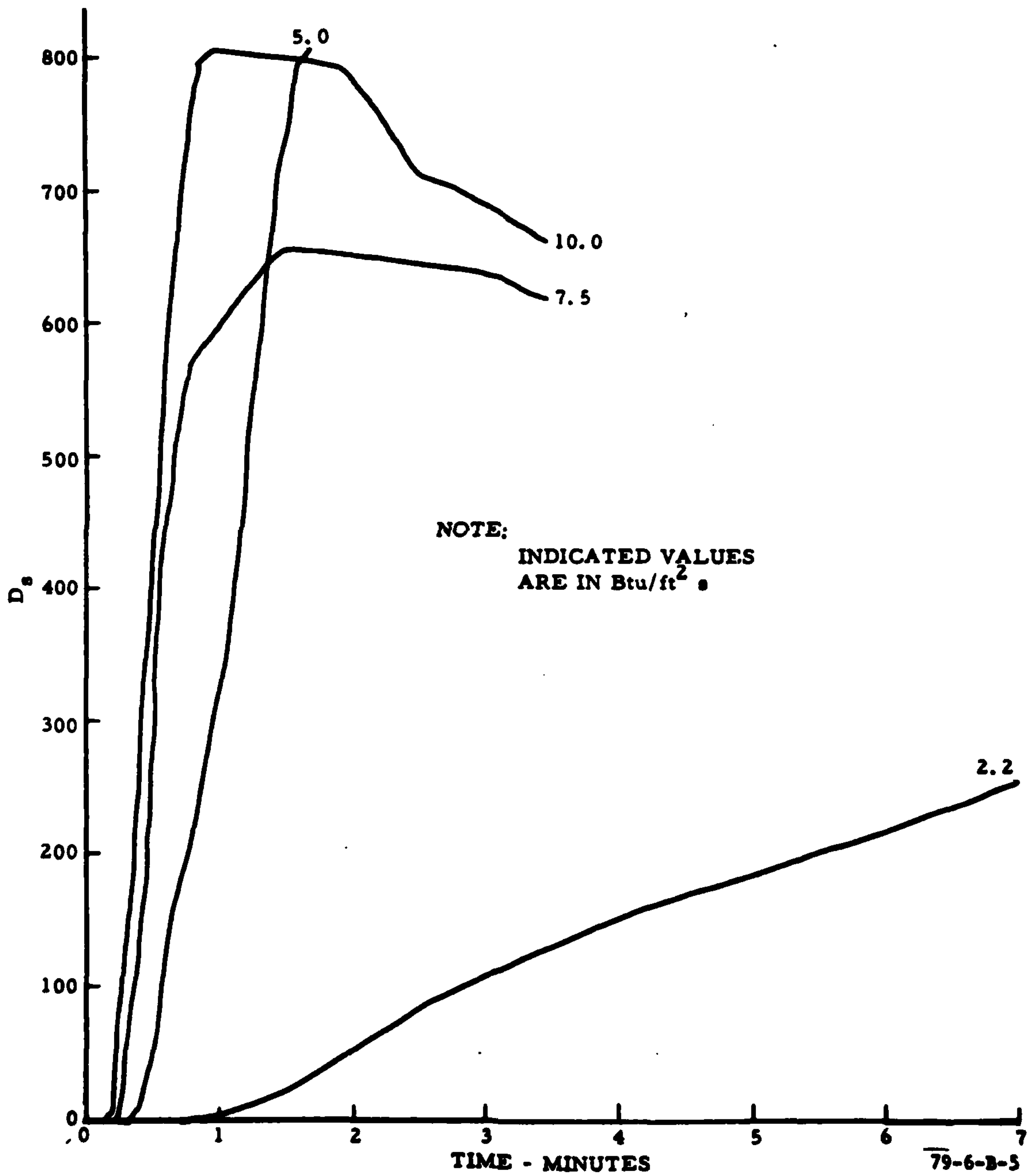

FIGURE B-5. PVC/COTTON (No. 210), NONPILOTED

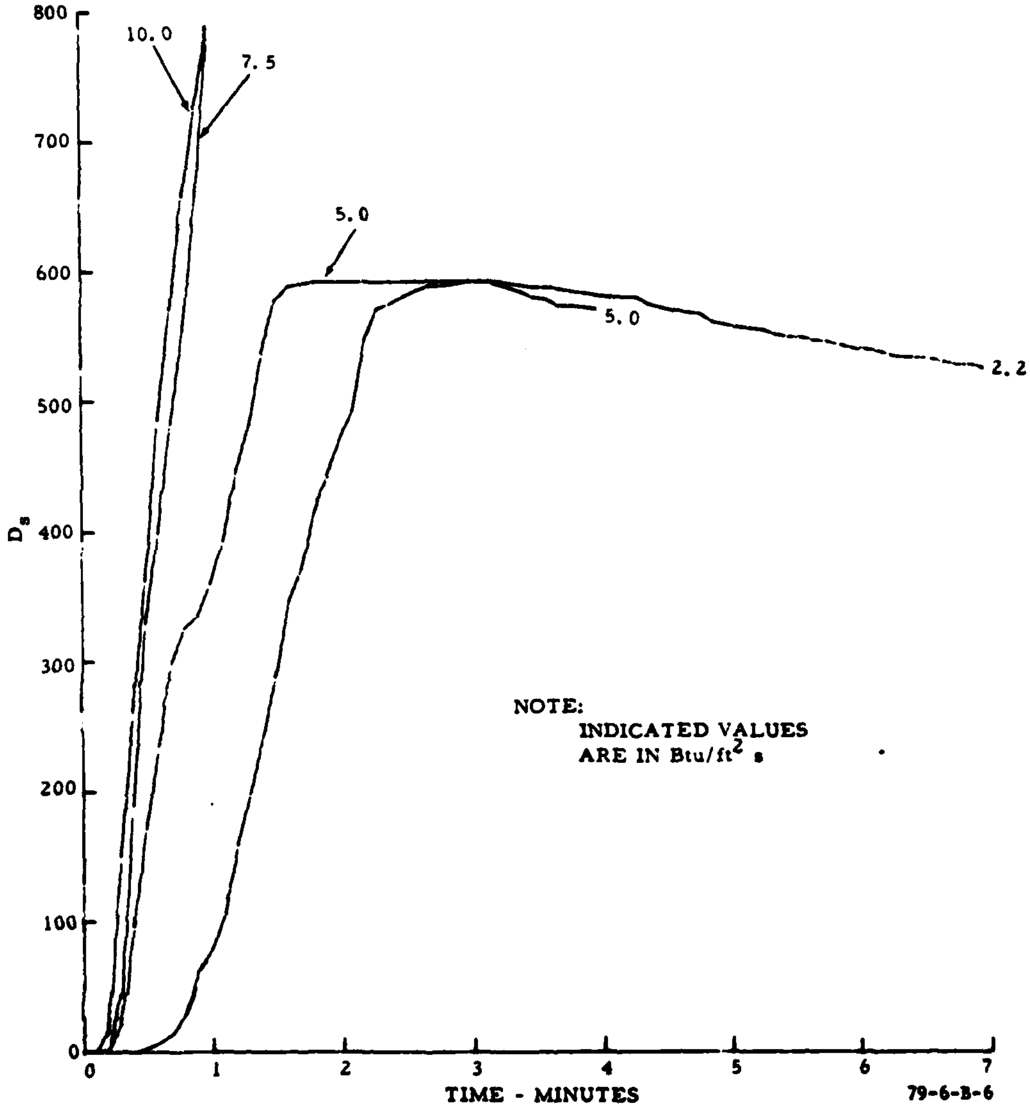

FIGURE B-6. PVC/COTTON (No. 210), PILOTED

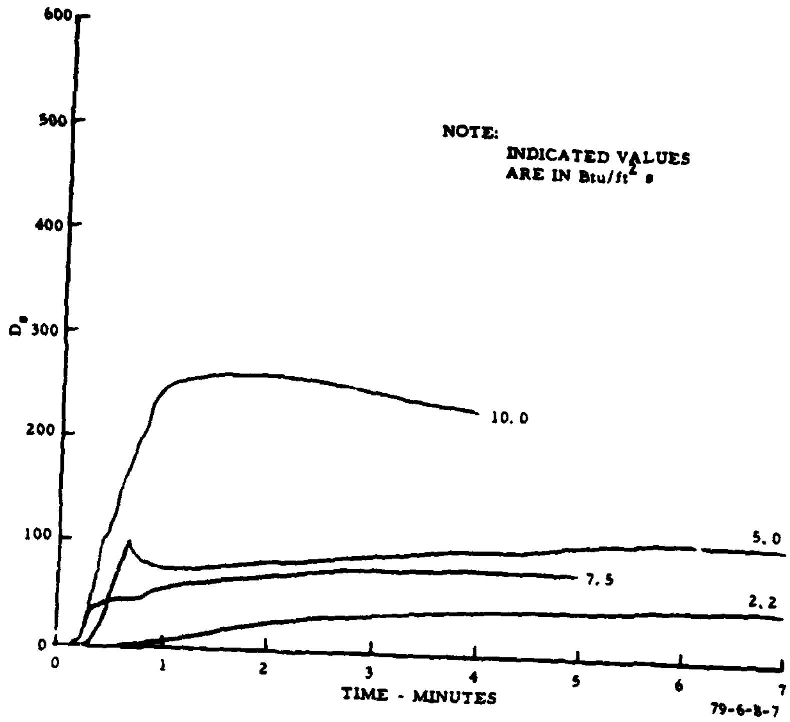

FIGURE B-7. WOOL 100% (No. 212), NONPILOTED

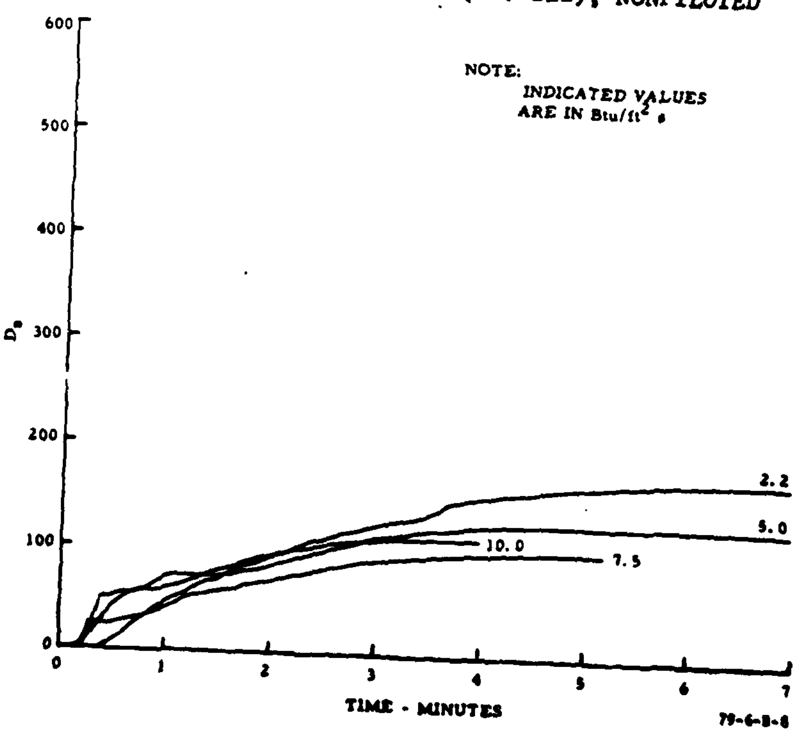

FIGURE B-8. WOOL 100% (No. 212), PILOTED

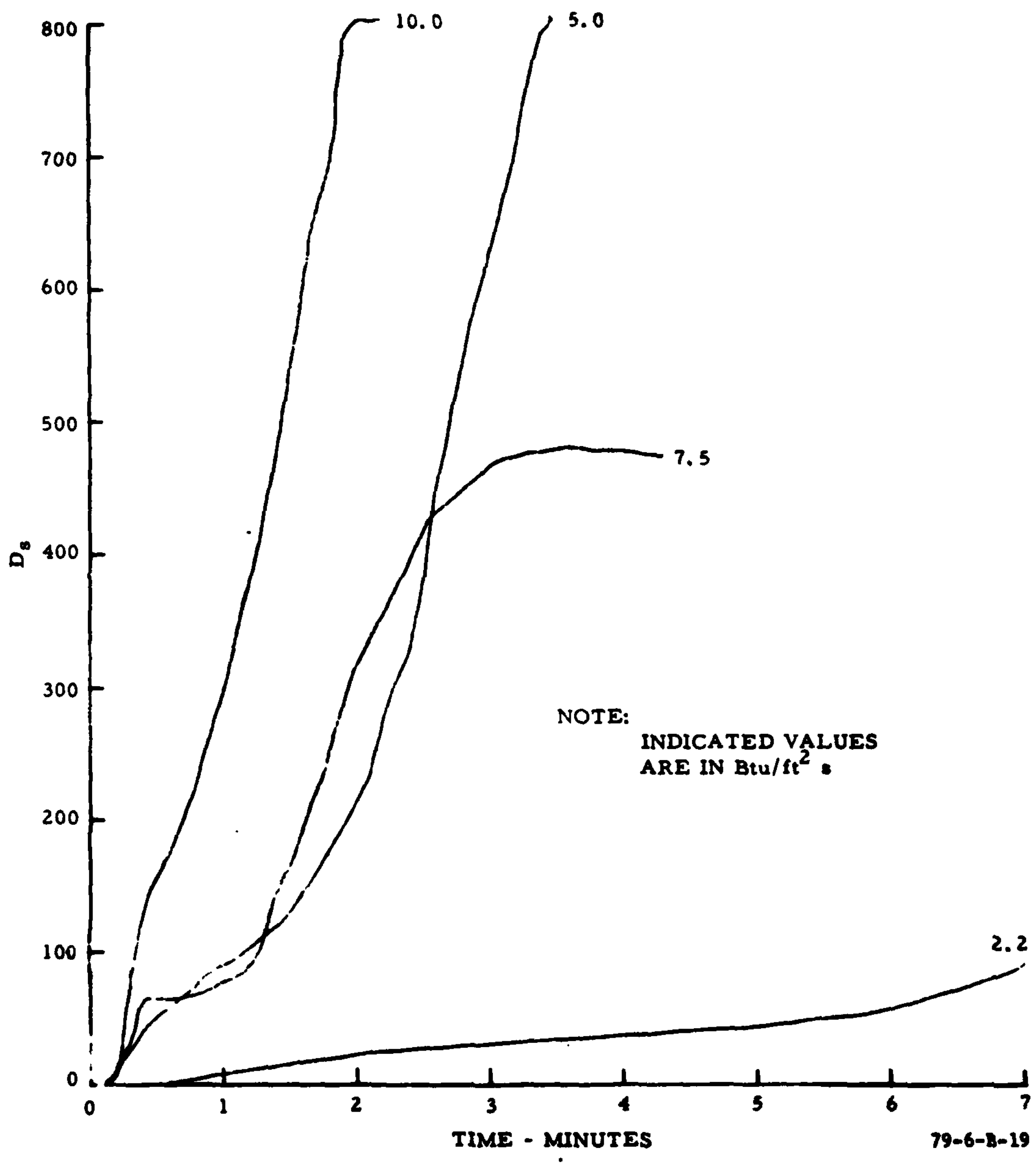

FIGURE B-9. WOOL CARPET (No. 226), NONPILOTED

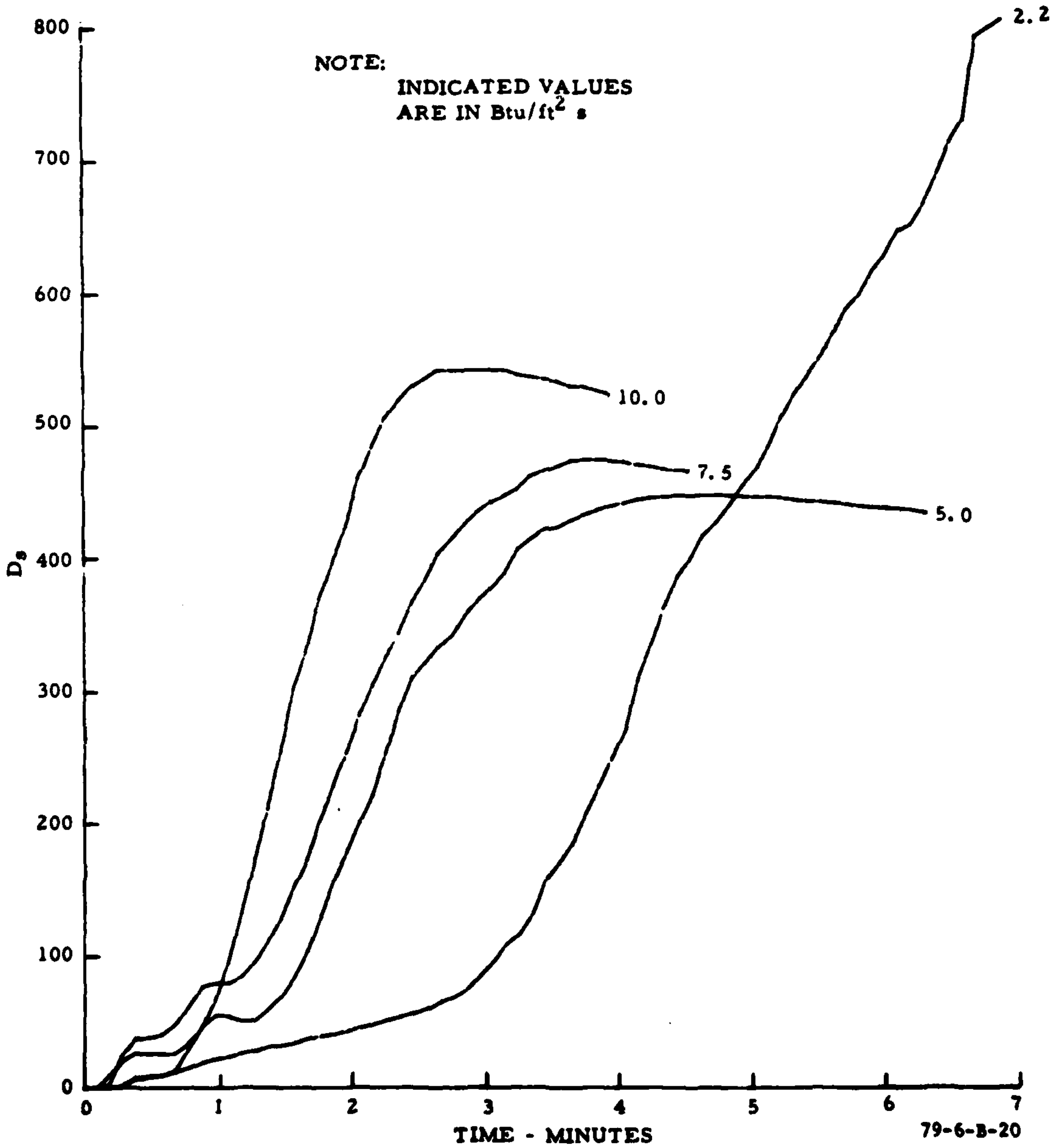

FIGURE B-10. WOOL CARPET (No. 226), PILOTED

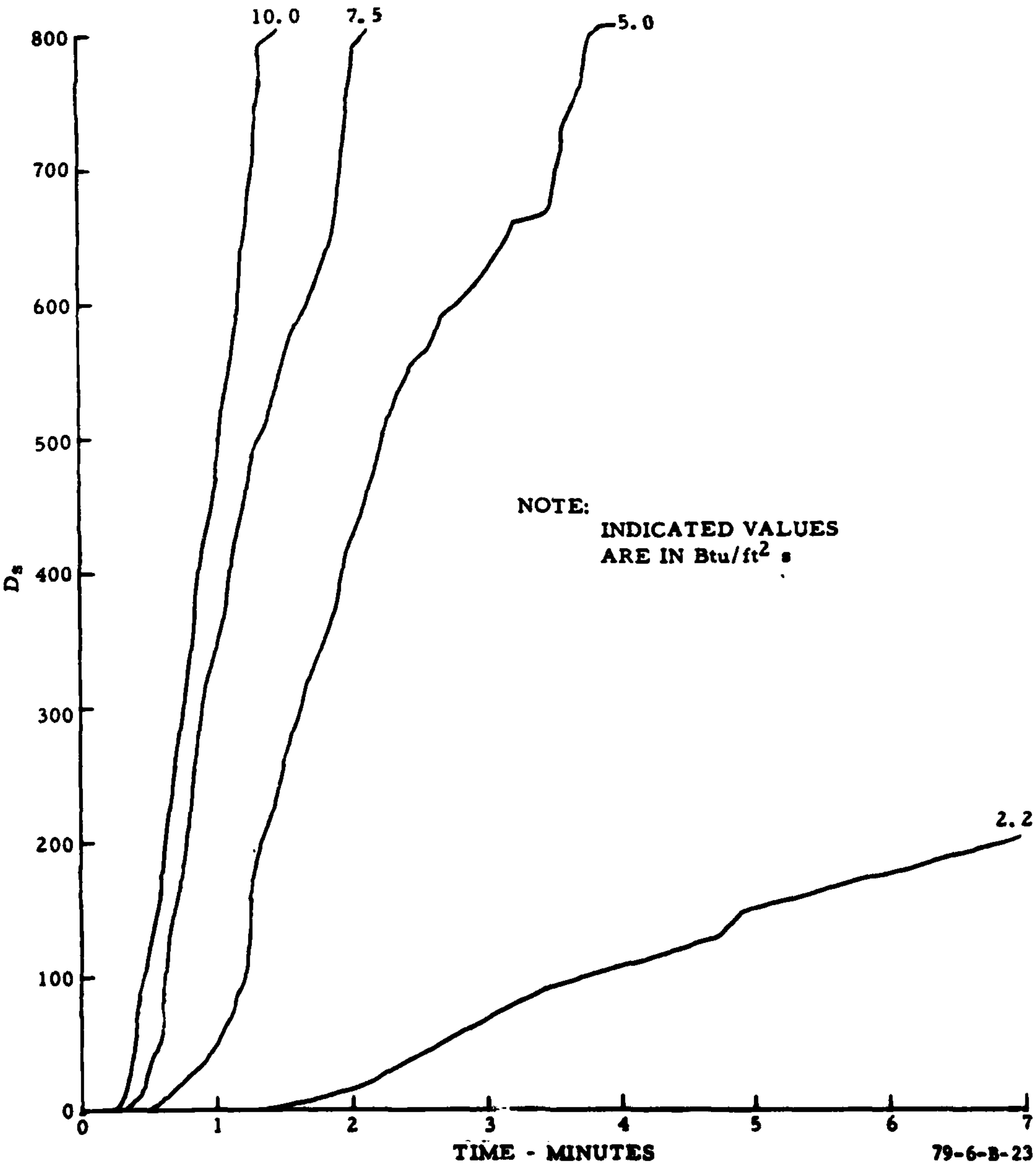

FIGURE B-11. VINYL/ABS FLOORING (No. 230), NONPILOTED

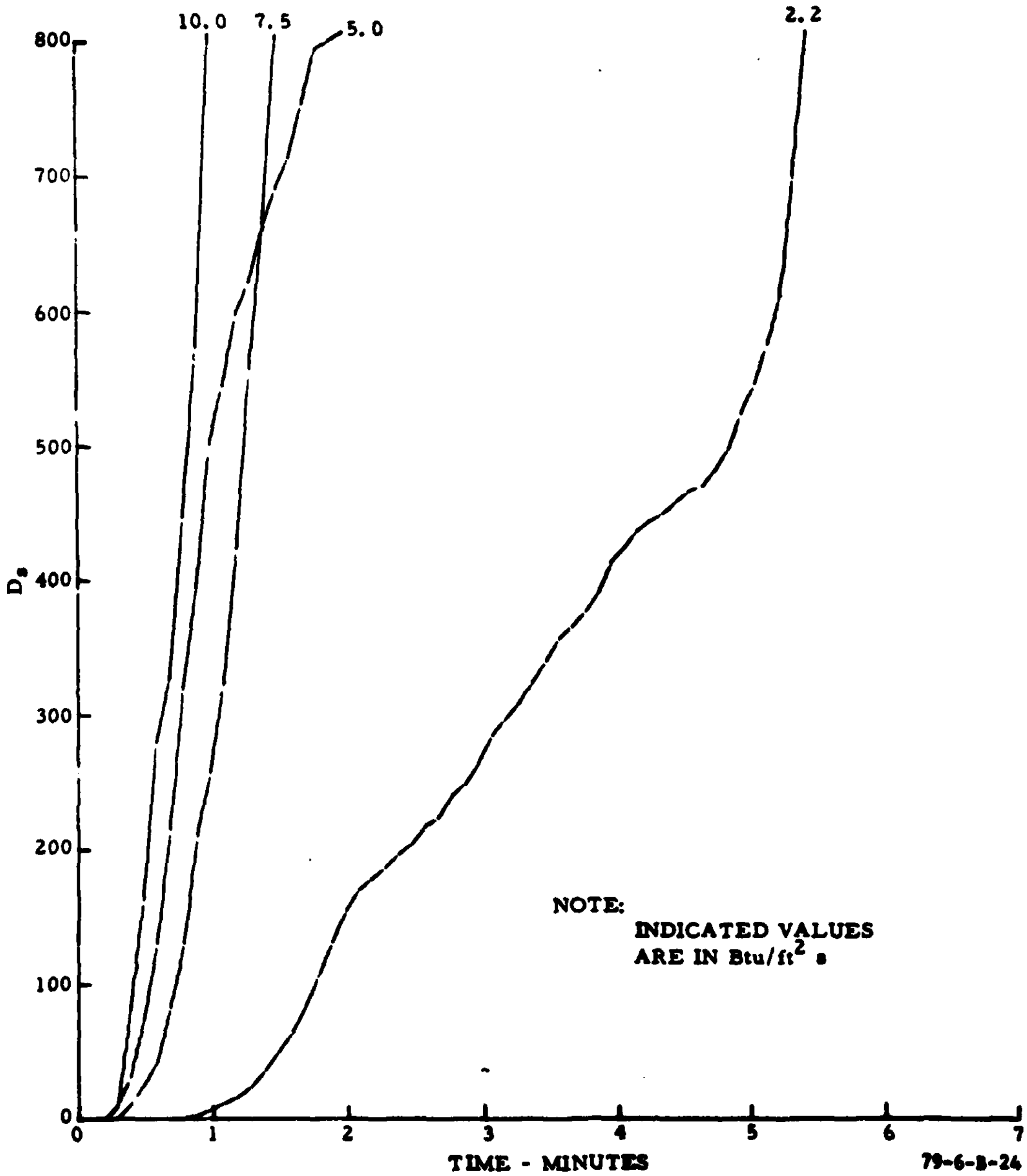

FIGURE B-12. VINYL/ABS FLOORING (No. 230), PILOTED

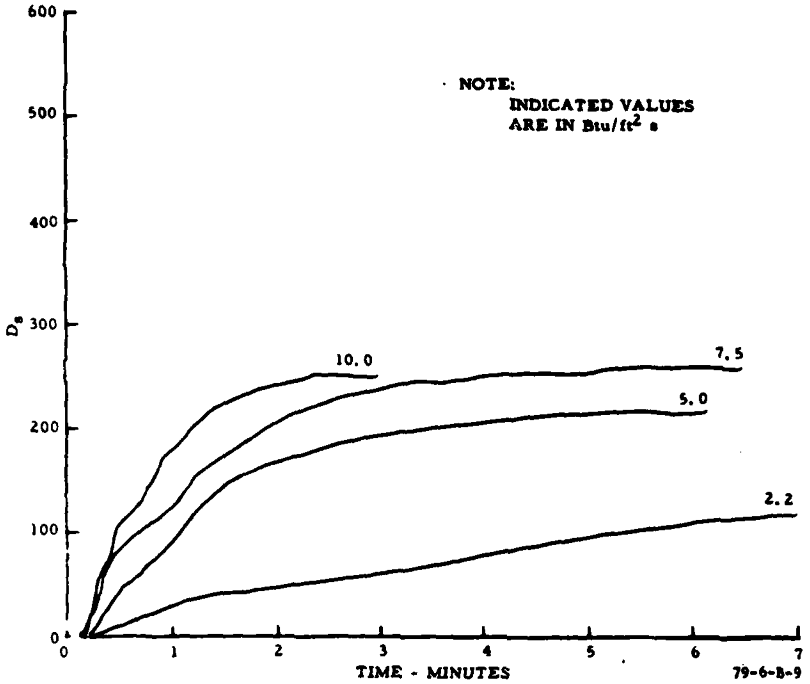

FIGURE B-13. POLYURETHANE (No. 213), NONPILOTED

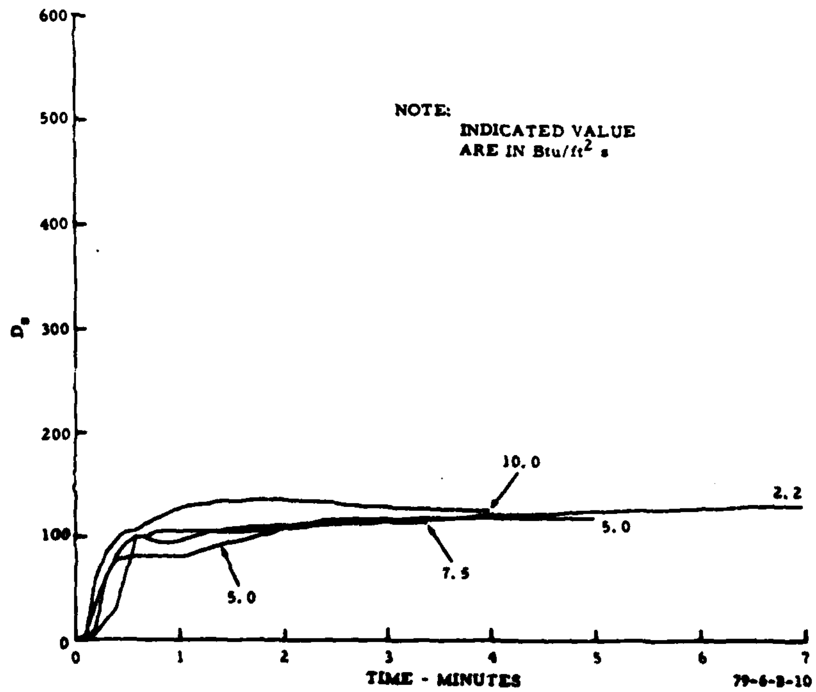

FIGURE B-14. POLYURETHANE (No. 213), PILOTED

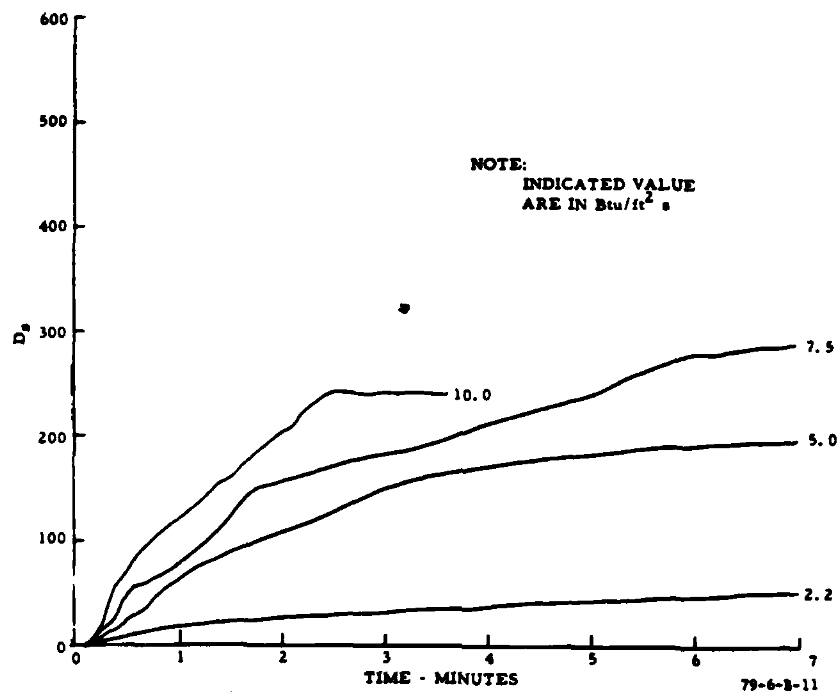

FIGURE B-15. POLYURETHANE (No. 215), NONPILOTED

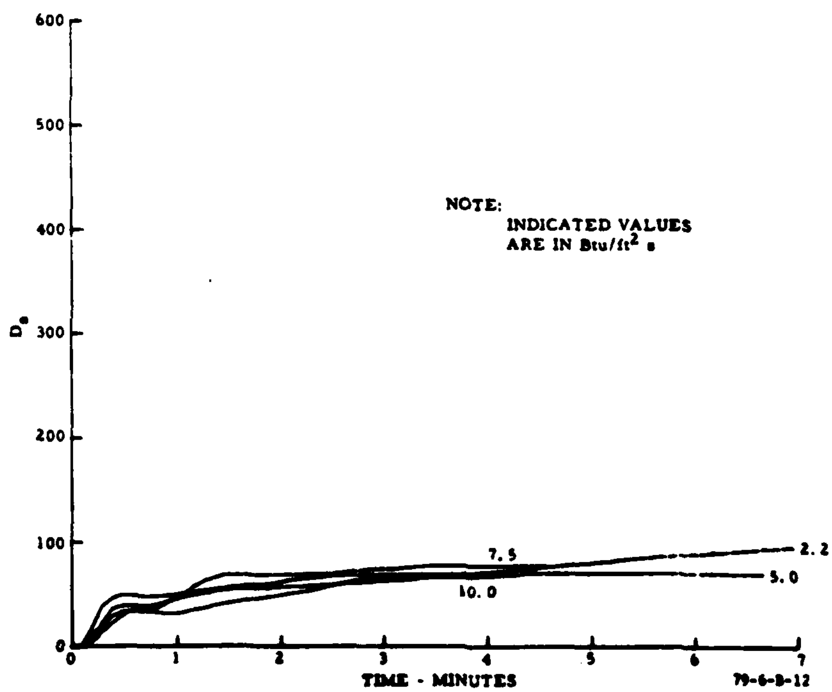

FIGURE B-16. POLYURETHANE (No. 215), PILOTED

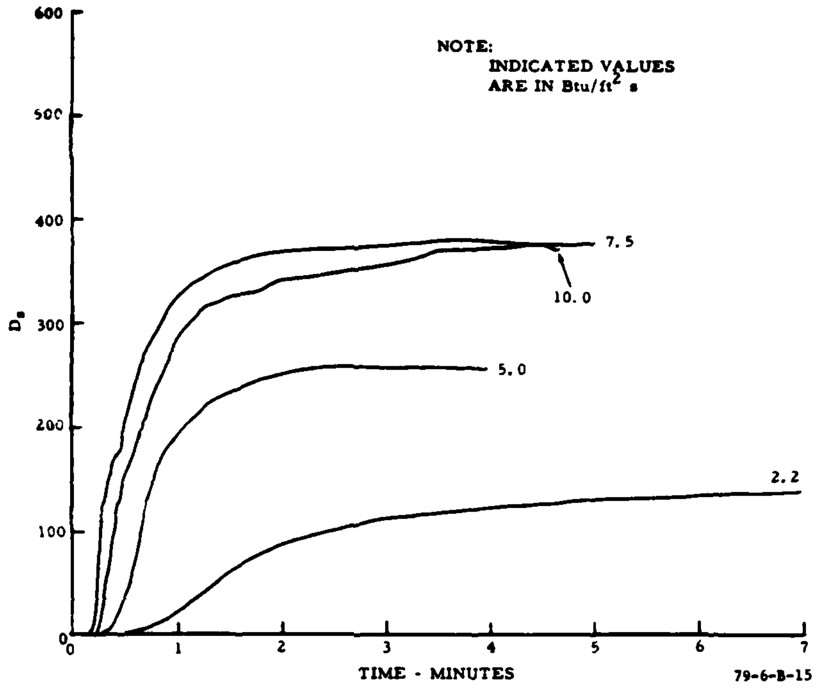

FIGURE B-17. CEILING PANEL (No. 224), NONPILOTED

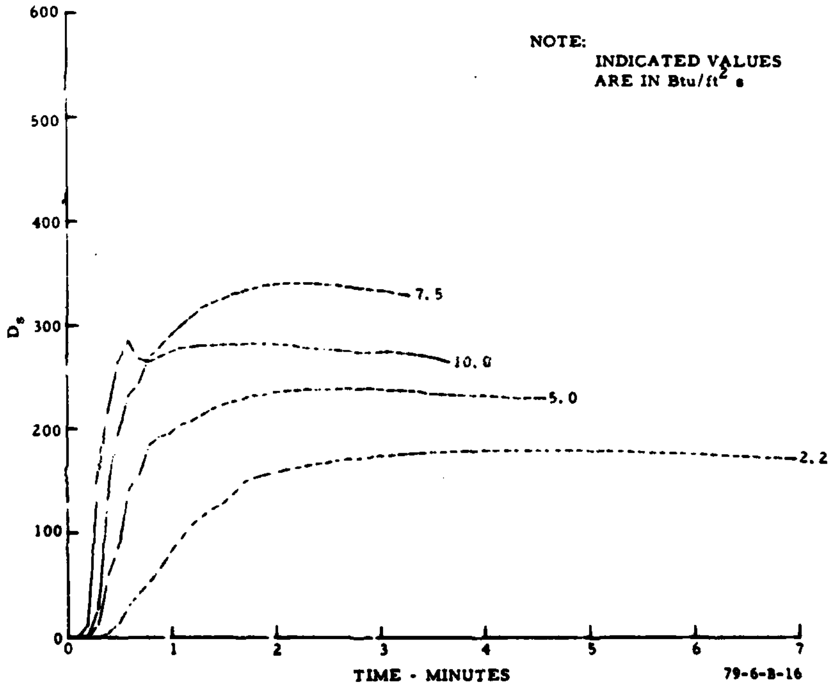

FIGURE B-18. CEILING PANEL (No. 224), PILOTED

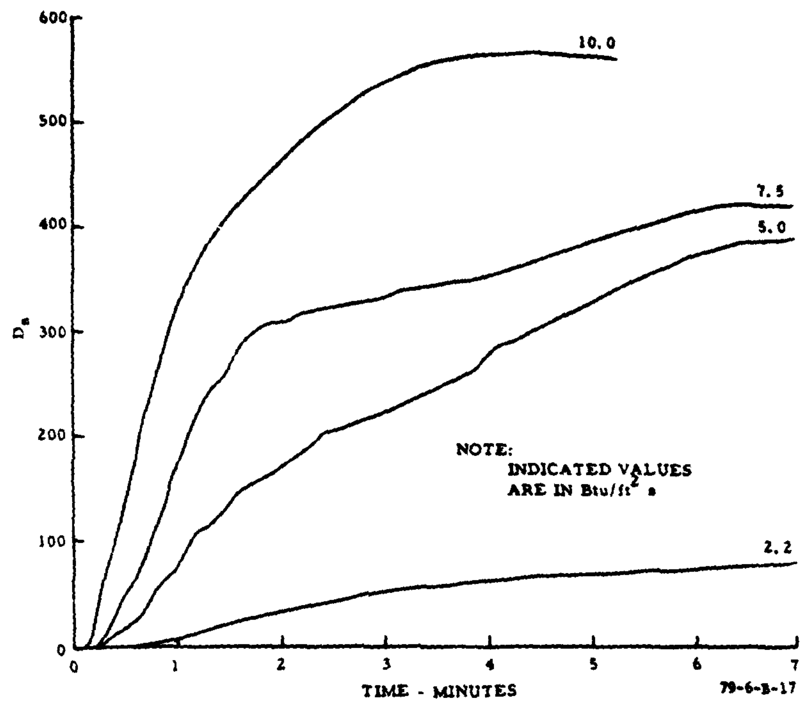

FIGURE B-19. OVERHEAD STOWAGE PANEL (No. 225), NONPILOTED

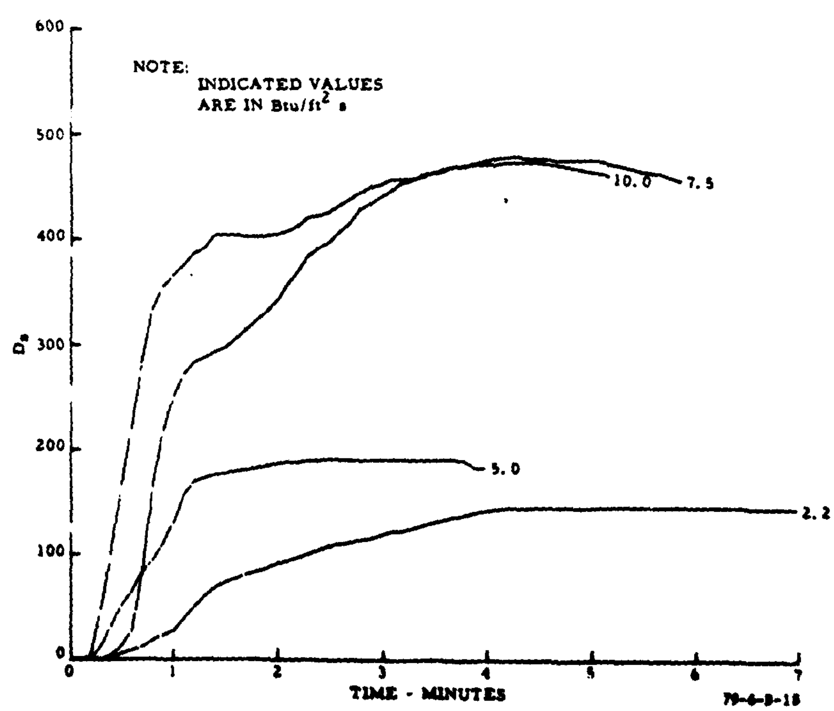

FIGURE B-20. OVERHEAD STOWAGE PANEL (No. 225), PILOTED

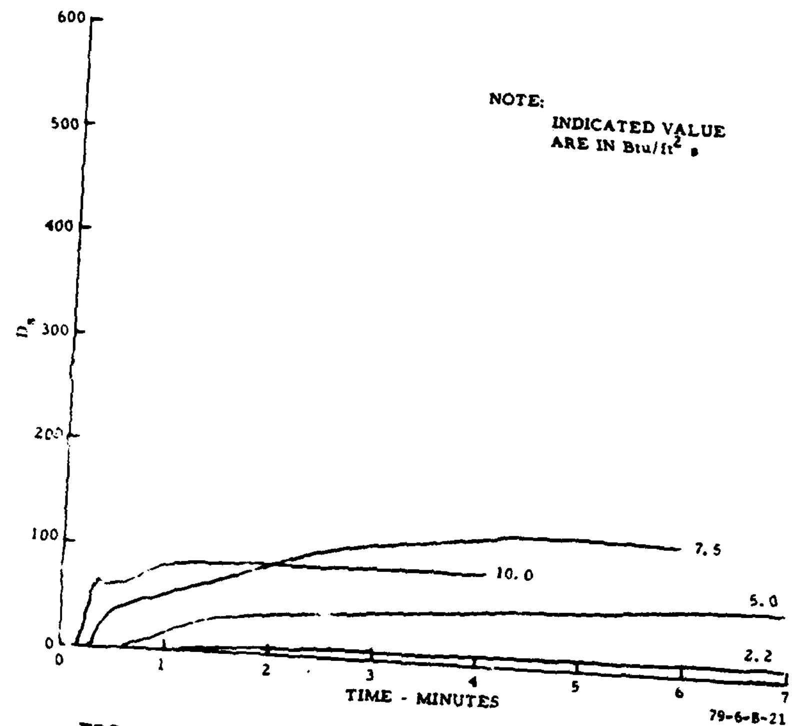

FIGURE B-21. SIDEWALL PANEL (No. 227), NONPILOTED

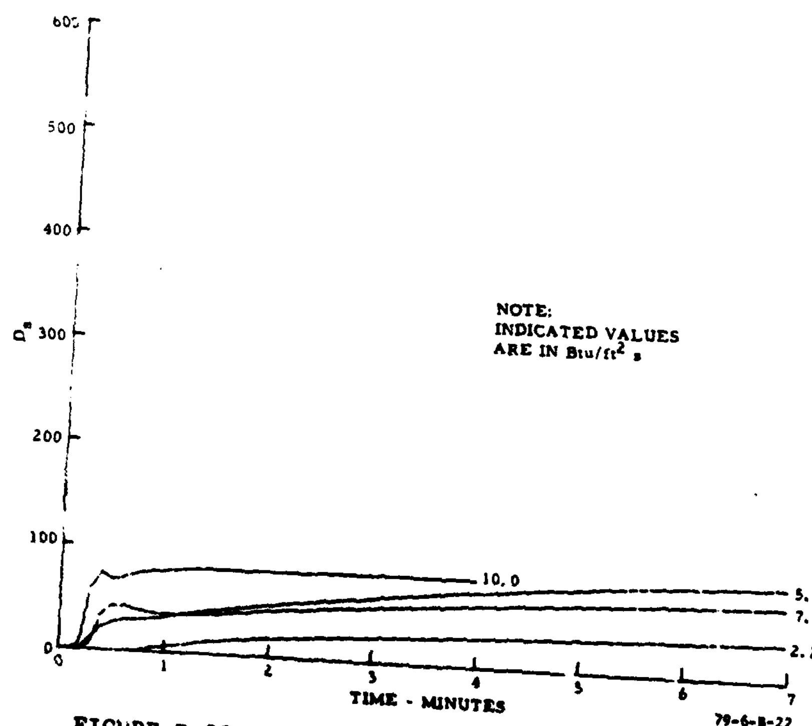

FIGURE B-22. SIDEWALL PANEL (No. 227), PILOTED

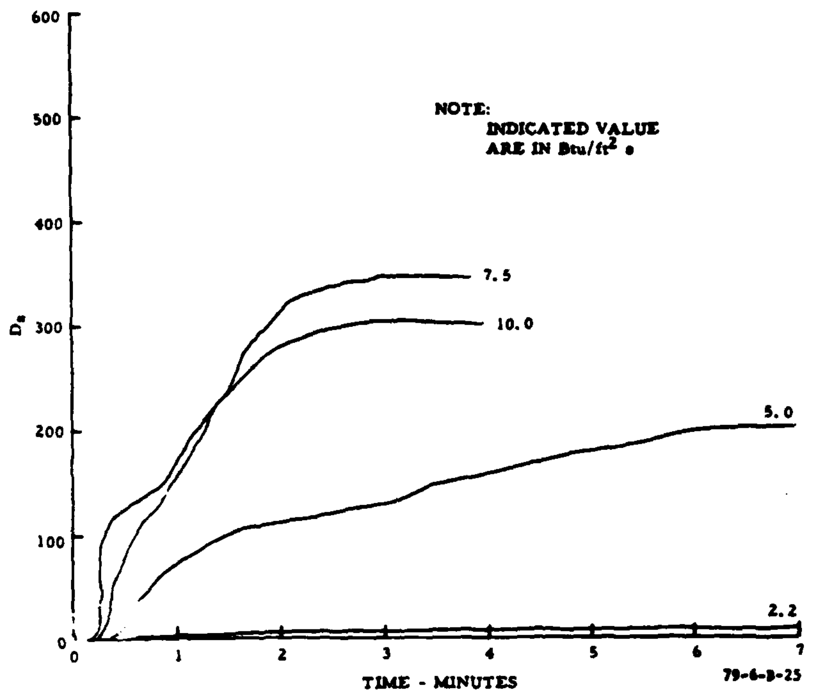

FIGURE B-23. SIDEWALL PANEL (No. 233), NONPILOTED

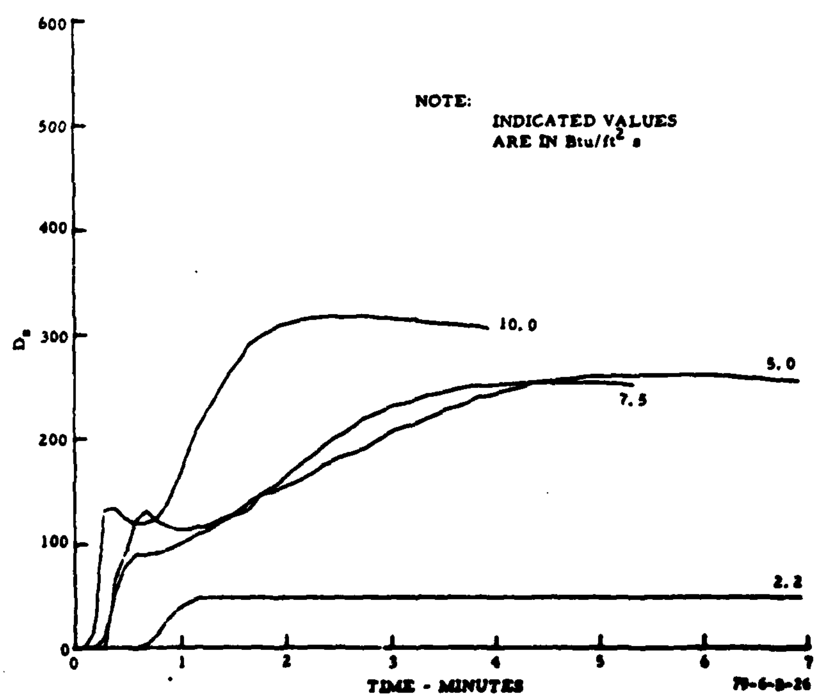

FIGURE B-24. SIDEWALL PANEL (No. 233), PILOTED

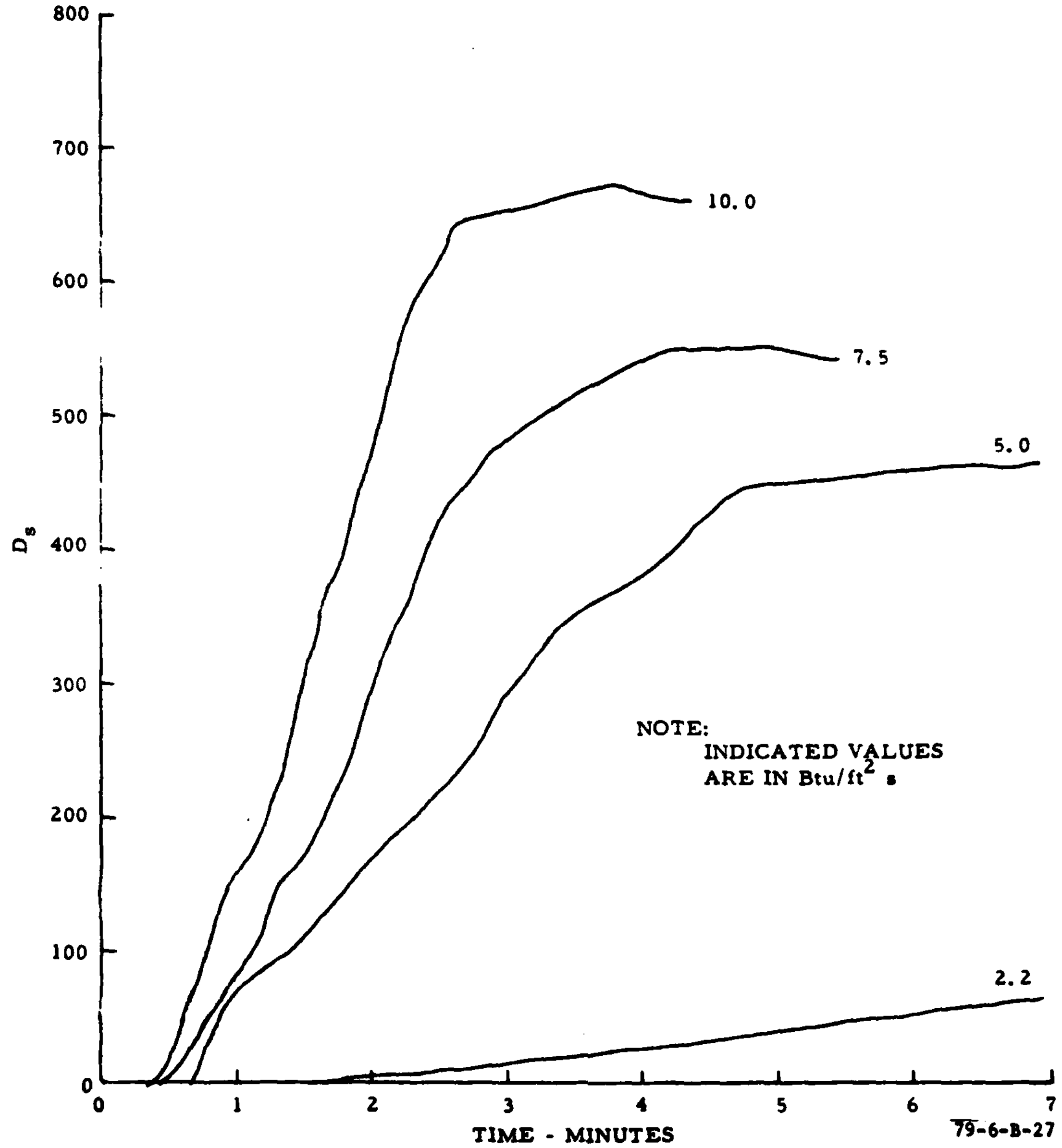

FIGURE B-25. CEILING PANEL (No. 234), NONPILOTED

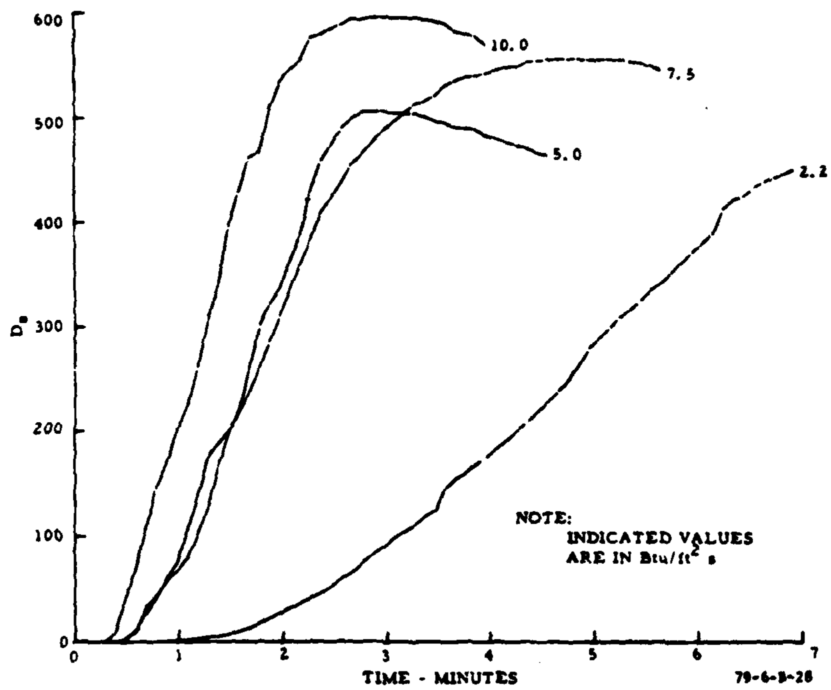

FIGURE B-26. CEILING PANEL (No. 234), PILOTED

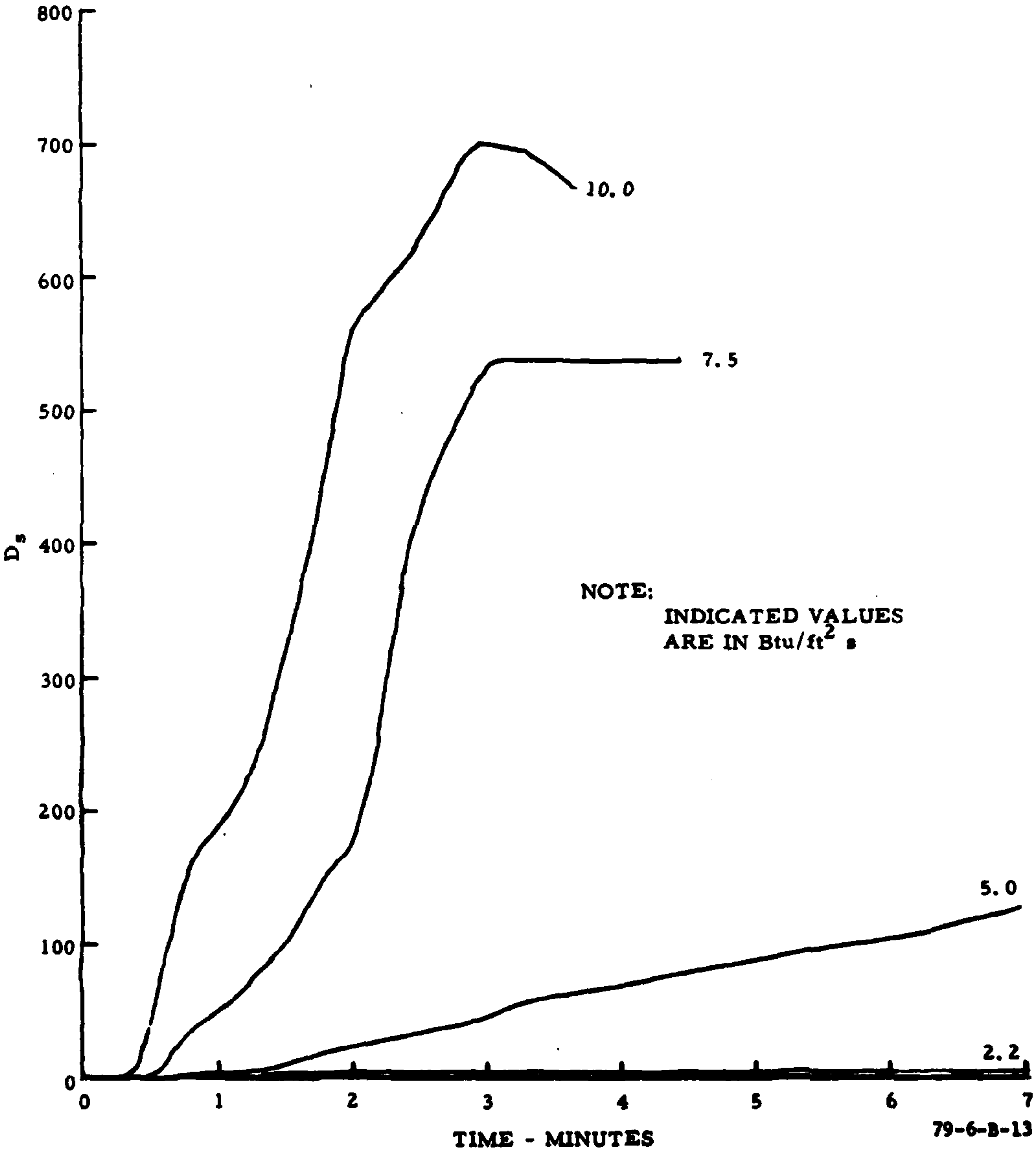

FIGURE B-27. POLYSULFONE SHEET (No. 220), NONPILOTED

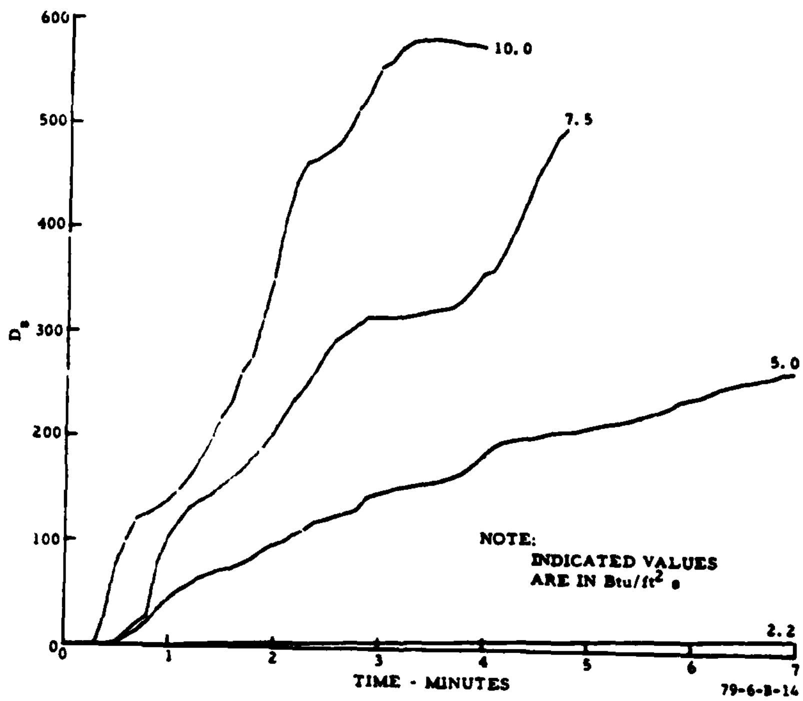

FIGURE B-28. POLYSULFONE SHEET (No. 220), PILOTED

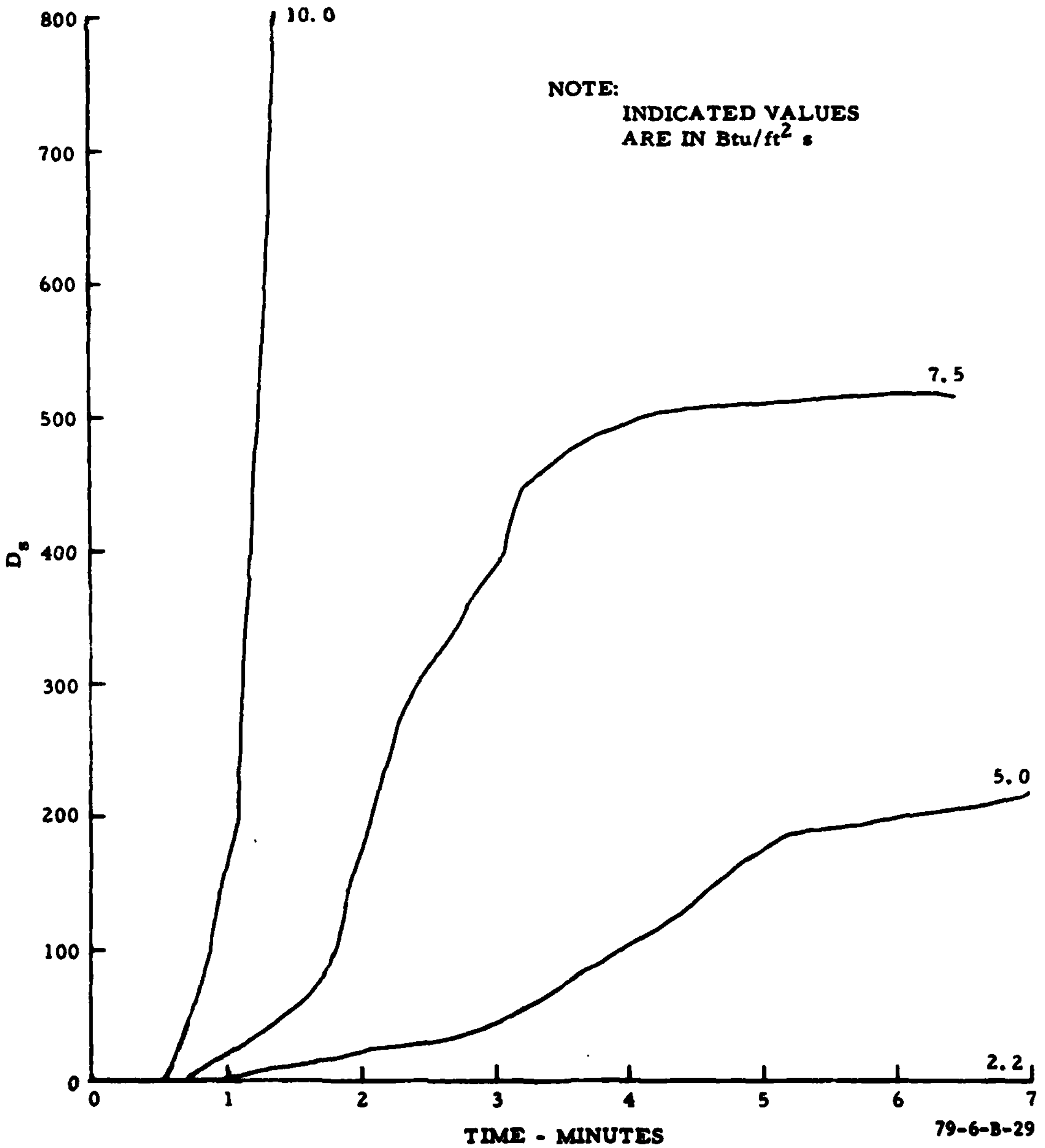

FIGURE B-29. POLYCARBONATE (No. 235), NONPILOTED

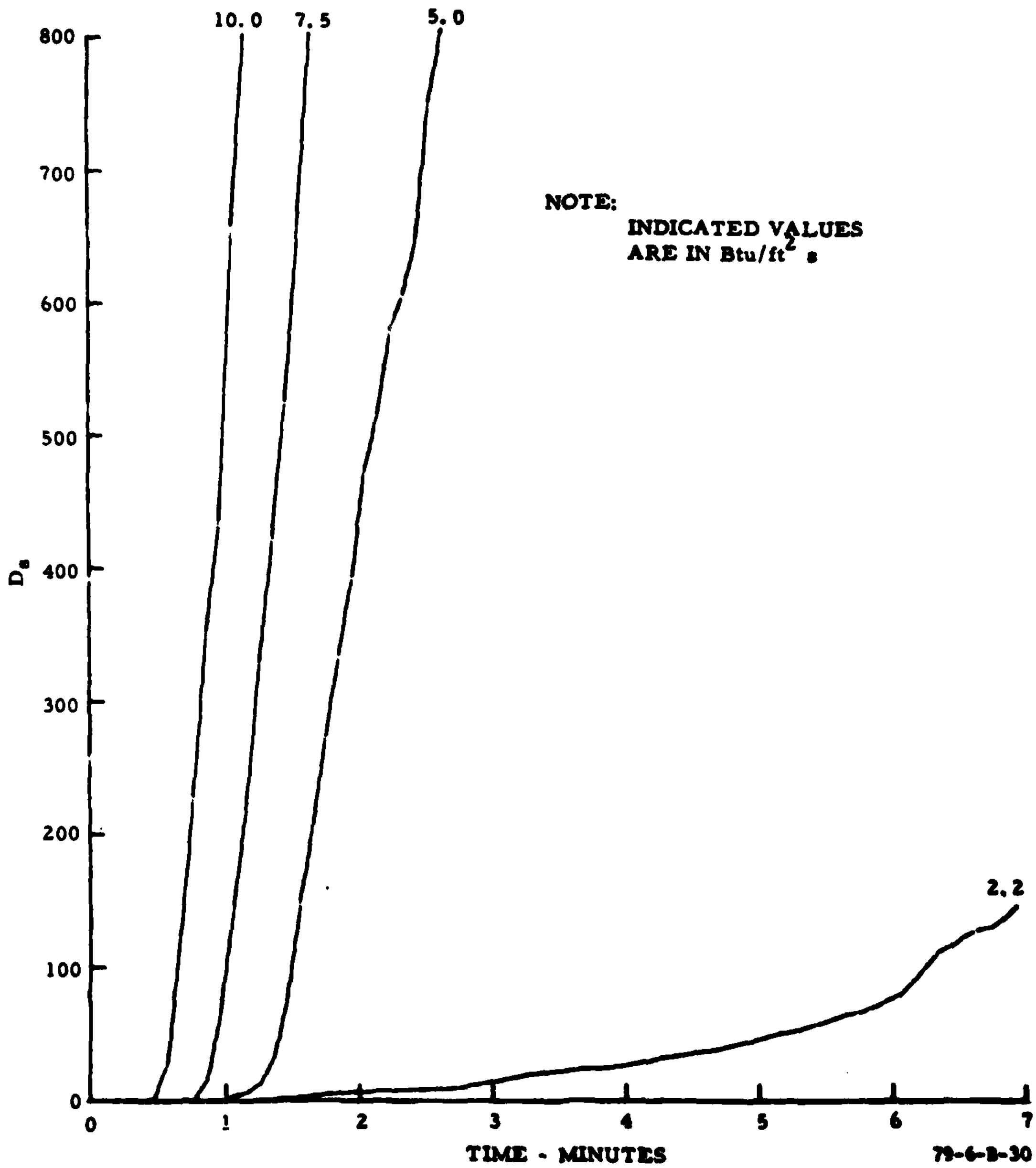

FIGURE B-30. POLYCARBONATE (No. 235), PILOTED

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